THE PREVENTION OF SMOKE

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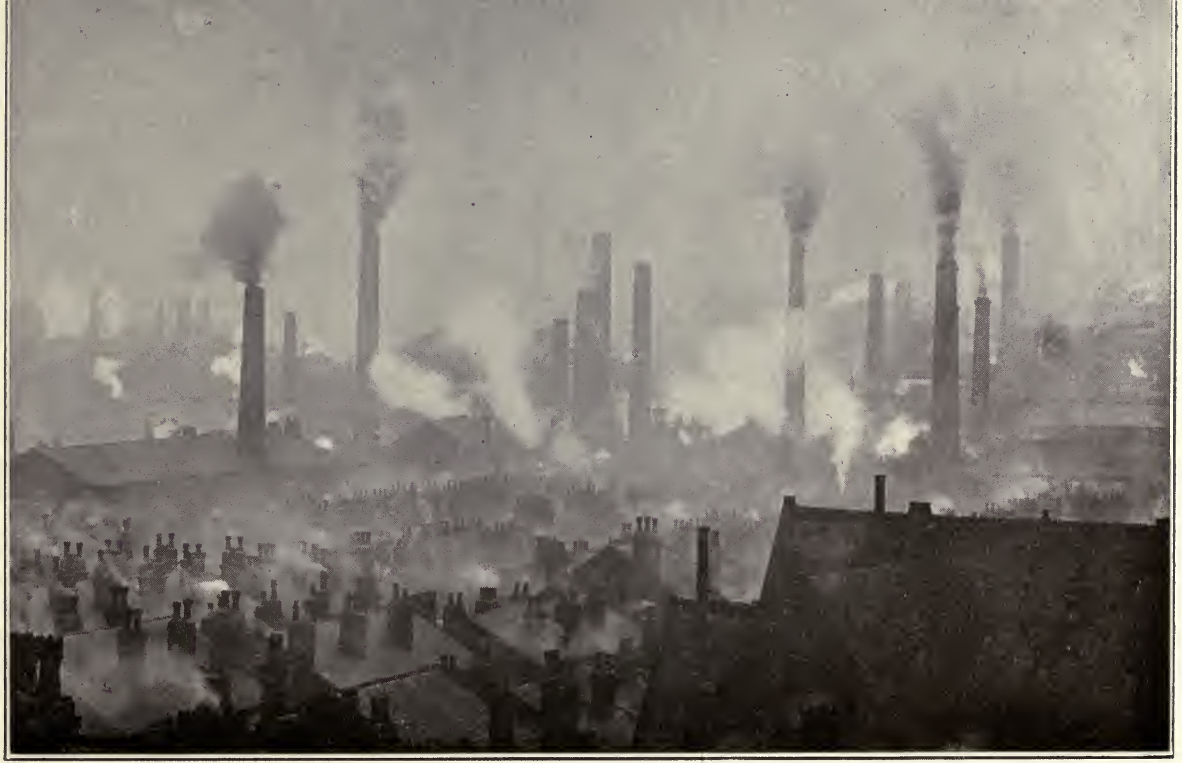

Group of Smoky Chimneys in the neighbourhood of Kirkstall Road, Leeds.

(The author is indebted to Dr. Cohen, of Leeds, for this view.)

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THE

PREVENTION OF SMOKE

COMBINED WITH

THE ECONOMICAL COMBUSTION OF FUEL

BY

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WITH FORTY-SIX ILLUSTRATIONS

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PREFACE.

The scheme of this little book is of the simplest. The greater part of the text may be said to consist of a brief statement of the principles which underlie the smokeless and economical combustion of fuel; a description of the most recent practice in burning fuel for commercial purposes; a *résumé* of a number of complete trials recently carried out, with the object of showing what are the best methods of dealing with coal for the purpose of steam raising, in a manner which is economical and at the same time smokeless; and, lastly, of a summary of the law as it relates to the smoke question.

It is hoped that the information brought together in these pages may be found useful to those who are particularly interested in this question of a purer atmosphere in our towns, as well as to steam users generally.

The author wishes to tender his acknowledgments for much valuable help which he has obtained from Mr. Bryan Donkin's valuable book on *Boiler Tests;* to Dr. Cohen and Mr. F. Grover, of Leeds, for their assistance in providing illustrations; and to the many engineers who have kindly lent blocks for illustrations of their own particular machines.

W. C. P.

Manchester, 1901.

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INTRODUCTORY.

The question of smoke prevention and abatement is not by any means one that has been confined to comparatively recent years. From the time when coal was first used in this country, the evils attending the emission of the black smoke from its combustion have been recognised, but have never been dealt with by sufficiently strong means so as to bring about a lasting remedy.

The black smoke in our atmosphere is entirely produced by the combustion of coal, either in small domestic fires or in the fires and furnaces devoted to commercial work. The exact date of the introduction of coal to this country is somewhat indefinite, but many authors give the ninth century as the period when it was actually discovered in England, and Henry III. is said to have granted the privilege of digging coal to the men of Newcastle; but it was not until long afterwards, in the sixteenth century, that coal was exported. It was about this period that ships were first employed for the purpose of bringing coals from Newcastle to London.

In these early days coal was spoken of as "stone coal," and we are told that a proclamation was issued in the time of Edward I., and another in Elizabeth's reign, prohibiting the use of stone coal during the time that Parliament was sitting, for the reason that the health of the Knights of the Shire might not suffer from this cause, while they were in London attending to their parliamentary duties!

Again, in 1648, the citizens of London petitioned Parliament to prohibit the importation of coal from Newcastle, on account of the harm that was being wrought upon the inhabitants of London by its use. But the evil was not nipped in the bud at this early period, and now, at the present time, we are perfectly content to suffer the emission of what must be an infinitely greater quantity of smoke into our atmosphere without a murmur, or at any rate without taking any very strong measures to abate it.

The subject was attacked in the time of the Stuarts. In a pamphlet written by Evelyn, in the reign of Charles I., it is said: "It is this horrid smoke which obscures our churches and makes our palaces look old; which fouls our clothes and corrupts the waters, so that the very rain and refreshing dews, which fall in the several seasons, precipitate this impure vapour, which, with its black and tenaceous quality, spots and contaminates whatsoever is exposed to it.

"It is this which scatters and strews about those black and smutty atoms upon all things where it comes, insinuating itself into our very secret cabinets and most precious repositories. Finally, it is this which diffuses and spreads a yellowness upon our choicest pictures and hangings; which is like Avernus to fowl, and kills our bees and flowers abroad, suffering nothing in our gardens to bud, display themselves or ripen; so that our anemones and many other choicest flowers will by no industry be made to blow in London or the precincts of it, unless they be raised on a hot bed, and governed with extraordinary artifice to accelerate their springing, imparting a bitter and ungrateful taste to those few wretched fruits which, never arriving at their desired maturity, seem, like the apples of Sodom, to fall even to dust when they are but touched."

These words of Evelyn, extracted from his *Fumifugina*, which was written more than two hundred years ago, very graphically describe the conditions which exist—in many cases in a more aggravated form—at the present day. He was so much impressed with the deleterious effects of the growing evil that he went so far as to have a bill prepared for its suppression.

The attempt at legislation made by Evelyn does not seem to have been properly followed up, and it is not until 1819 that we again hear of any very definite statement on the smoke question. In a report of a Select Committee of the House of Commons we find these words: "We confidently hope the nuisance so universally and justly complained of may at least be considerably diminished, if not altogether removed". Again, in 1820, the subject was still being followed up, and in a report we find "that a full opportunity has been afforded of ascertaining how far the reduction of smoke can be practically effected, and that the evidence taken bears out the practicability of smoke prevention".

From the year 1820 to the present day various Acts have been passed, or clauses of Acts, specially referring to smoke abatement, have been enacted. But, in spite of all this, the evil has been growing worse year by year, the law having to a great extent failed to effect any real improvement. The legal aspect of the case will be considered later, and for the present it is sufficient that no one will deny for a moment that the large quantities of smoke emitted from our house and factory chimneys constitute a nuisance which it behoves all classes of society to do their utmost to eliminate.

The evils of the pollution of the air by smoke are not difficult to appreciate. The real difficulty lies in bringing the people who are responsible for the emission of black smoke to so far recognise the extent to which they are doing harm as to do their best to limit the output of smoke to the lowest possible extent, compatible with the efficient and successful working of their furnaces or fires. The production of black smoke may be broadly divided into that emitted from the chimneys of house fires, and the smoke sent out from the chimneys of factories and metallurgical furnaces. It is rather a disputed point as to which is the greater sinner in this respect—the house fire or the commercial furnace, whether boiler or metallurgical. It is really a question of simple arithmetic: where the district considered is entirely residential, such smoke as is produced is wholly that from house fires; and in the case of communities entirely given up to manufactures, such as are to be found in many parts of the North of England, the greater part of the evil is due to the smoke emitted from furnace chimneys, chiefly from steam boilers. It is the factory chimney smoke that is the most easily seen, and therefore it is a common error to blame the pollution of the atmosphere by smoke entirely upon this. It is quite certain that a very large amount is due to the multitude of individually small quantities of smoke issuing from the chimneys of dwelling-houses.

The evil is most aggravated in a thickly populated neighbourhood, having in its midst a large number of smoke-producing factory chimneys; and the effect is worse for the neighbourhood itself if the land is low-lying or is sheltered by high hills, so that there is no possibility of the smoke getting freely away, as would be the case if the town were in an exposed and breezy situation. Such places are to be found in the lower parts of towns like Sheffield and Leeds. Of course it must be remembered that when the smoke-laden atmosphere is dispersed, the smoke will be deposited over a larger area instead of falling near the place where it has been produced, the evil being still there, but in a more diluted and widely distributed form.

Evils Resulting from a Smoky Atmosphere.

The gases issuing from a chimney consist, firstly, of an invisible portion made up for the most part of innocuous gases which exist in the atmosphere in such minute quantities as to be capable of doing no material harm. This is true for the gases from fires, and does not refer to the fumes from the chimneys of chemical works, which are capable of doing a great amount of damage. Besides the invisible portion of the gas, there is the visible portion, consisting for the most part of minute particles of carbon, which is not entirely pure, but contains a certain amount of sticky, tarry matter. The smoke, after issuing from the chimney, becomes dispersed in the air to a height of some hundreds of feet above the ground. This widely distributed smoke gradually settles, clinging to anything that presents itself. The ground, the walls and roofs of buildings, the trunks, branches and leaves of trees and shrubs, the exposed parts of the person and the clothing, all come in for a share of the all-enveloping cloud. Where the surfaces are smooth and exposed to the washing action of the rain, as in the case of roofs of buildings, very little of the dry carbon itself remains, but only the more sticky substances, which cannot so easily be washed off. Rougher surfaces, such as stone walls, and especially trees and shrubs, retain the black dirt far more readily, and become permanently coated with a sticky, sooty film.

From an æsthetic point of view the effect of smoke is as bad as it can be. In our large manufacturing towns, where the atmosphere is very heavily laden with soot, all the stone buildings become, in a very short time, nearly black, the stone presenting a more retentive surface than the smoother brick though the brick buildings do eventually become coated in much the same way. Those who know the Leeds Town Hall, one of the finest buildings in the country, cannot fail to appreciate the terribly disfiguring effects of exposure for a few years to an atmosphere heavily laden with black smoke; or, remembering what the Manchester Town Hall was like in its early days, and looking at it now, one feels that this disfigurement of public and private buildings, though only one of the lesser evils of black smoke, is sufficient reason for the most vigorous crusade against those who, by their negligence or obstinacy, contribute to the pollution of our atmosphere.

The disfigurement of buildings is, perhaps, less objectionable than the coating of black which settles on all the vegetation in a district pervaded by smoke, for, besides the dulness imparted to the colours of the plants and trees by the layer of soot, the blackness of the trunks and branches of the trees, and the unpleasantness in touching, or allowing portions of one's clothing to touch these, there can be little doubt that the vigorous growth of a plant is, to a large extent, interfered with by the presence of a film of an oily substance on the surface of the leaves. At the same time, much of the unhealthiness of plants attributed to smoke is very likely due, not so much to this, as to the presence in the atmosphere of deleterious acids, which are formed along with the smoke; the breathing pores of a plant are on the under side of the leaves, and it is on the upper surface that the greatest deposit of soot takes place, though some small quantity also clings to the under side.

The atmosphere is what we breathe, and upon it we depend for our very existence, and it is therefore necessary that we should be as careful that we breathe pure air as we are that the water which we drink is without contamination. Life in a smoky and crowded town is not, and cannot be, so healthy as a life which is spent in a pure atmosphere, free from the contaminating effects of smoke and its accompanying products. It is well known that the urban population is tending to deteriorate, and is only kept up to a reasonable standard by the continuous influx of workers from the country districts, the tendency being for people to crowd to the towns for work and higher wages. The town population is increasing rapidly year by year, and there is a corresponding decrease continually taking place in the number of inhabitants in the country districts. Though in many directions the conditions of town living are being improved—greater attention is being paid to sanitation, the dwellings of the working class are on the whole improving, and the public authorities are waking up to the necessity for plenty of open spaces—still the two facts remain, that the population in the smoky areas is very much on the increase, and that the atmosphere in these areas does not, to say the best of it, improve.

Dr. A. Ransome has stated definitely that the existence of a smoky atmosphere has an undoubted influence in increasing mortality. This is a statement well worth consideration, coming as it does from an eminent authority on the question of Public Health. Dr. Ransome also insists very strongly that one effect of a smoky atmosphere, even worse than that of breathing the vitiated air, is to be found in the indirect effect of the dirtiness of the air, in causing people to keep their windows shut in towns, and so breathe the even more vitiated atmosphere within. It has for some time been recognised that one of the conditions most favourable to consumption is to be found in defective ventilation.

Another effect of a smoky atmosphere, and one often lost sight of, is the effect that the presence of soot in the air has in shutting off and obscuring the sunlight, which is so important to healthy life. This may easily be noticed on going into a large town by train from a clear country atmosphere. As the town is approached the sunlight gets less intense, and often in the winter months it is found to be nearly dark when the centre of the town is reached. This is always so to some extent, the only variation being one of degree.

A striking illustration of this is to be found by going into the centre of a large manufacturing town on a Sunday, when the factories and workshops are closed, and there are fewer house fires burning. One notices at once how very much brighter everything looks than on a working day, and this difference is chiefly due to the clearer atmosphere overhead.

Many other instances might be quoted of the deleterious effects of a smoky atmosphere, such as the blackness and dirtiness of birds which ought to be white, as hens, pigeons and ducks; the frequency with which white curtains have to be washed in the neighbourhood of manufacturing towns, where they only last days, when they would remain clean the same number of weeks or months in the country, away from the smoke; and the trouble we have in keeping our linen, books and furniture clean.

INFLUENCE OF SMOKE ON FOGS.

There is little doubt that the presence of smoke in the atmosphere assists very largely in the formation of fogs. The smoke in the air becomes generally diffused, so that the whole volume of the atmosphere gets to consist of pure air throughout which are numberless small particles of carbon, each one of which may serve as the nucleus of a foggy globule. In certain states of the atmosphere as to dryness, pressure, temperature and stillness, the aqueous vapour becomes partially condensed, it being generally supposed that each carbon or dust particle acts as a nucleus around which collects a small globule of moisture, the summation of these making up the yellow fog with which our largest towns are so greatly oppressed during each winter. A reduction of the number of smoky particles in the air might be expected to reduce the density and dirtiness of our fogs, if not to do away with them altogether. Fogs are not confined to towns, but the fog of the country is a white innocuous mist, which may be unpleasant in some ways, but it never assumes the density of the real town fog, nor does it soil the linen, nor make the eyes smart and clog the lungs of all persons exposed to its effects.

It is stated that there are about fifty tons of soot and two hundred and fifty tons of carbon dioxdide in the atmosphere immediately above London, and this in spite of the fact that the means taken for the prevention of the emission of black smoke are much more definite, and the laws relating to smoke are much more stringently enforced, than in other cities and towns in the country. No doubt the smaller industrial fires and the domestic fires are to some degree responsible for any smokiness which is found in the neighbourhood of London. But, although many people are fond of insisting that the smoke evil is due to house fires to a greater extent than to factory furnaces, the fact remains that in places like the West End of London, Edinburgh, and other large towns where industrial operations are few, the atmosphere is without a doubt purer in every way; buildings are cleaner, trees and plants flourish, and the appearance of everything is brighter than in any town where there are a number of factory chimneys pouring out smoke and sulphurous gases.

Some interesting and valuable results were obtained a few years ago by Dr. Cohen, of the Yorkshire College, Leeds, in connection with the quantity of smoke to be found in Leeds, one of the smokiest of cities. These results were published by him in pamphlet form in 1896; and I here desire to acknowledge my indebtedness to Dr. Cohen for much information and many valuable hints.

Dr. Cohen found that in every 100 cubic feet of Leeds air there were about 1·2 milligramme of soot. This he did both by estimation from the amount of coal burnt per day in Leeds, and also by the more direct method of collecting known volumes of the air, separating the soot, and weighing it. He estimated the amount of coal burnt per day in Leeds as 4,000 tons, and, of this, that one half per cent. escapes into the atmosphere as soot. This gives about twenty tons of solid smoke sent into the atmosphere, and of this, Dr. Cohen found by weighing the soot collected from melted snow, that "half a ton falls on the immediate area, and of this twenty to twenty-five pounds sticks, or is not removable by rain".

After glancing at the above facts and figures it should be clear that the smoke evil is not an imaginary one, and that much real harm is being done by the emission of black smoke from the chimneys in our towns. That the production of smoke in objectionable quantities is preventable is recognised by most competent authorities on the subject. In the following pages the writer wishes to explain what are the methods which have been adopted, and which have been found to be the most satisfactory, both from the point of view of the general public who suffer from the emission of smoke, and from that of the person who uses the fuel for his own benefit, and is therefore responsible to the public, and is the proper person to take any measures for improving the chimney gases.

As science progresses, the whole system by which we utilise our fuel for light and power will in all probability undergo a complete revolution, and much of the smoke difficulty will be automatically solved. But at the present time the individual is allowed too much liberty as regards what he puts into the rivers and into the atmosphere. There are certainly laws to deal with the offenders, but the legal machinery, as it at present exists, is too cumbersome to be capable of producing any far-reaching improvement. An individual who is one of a community of many must be made to recognise that he must not do that which will produce ill effects on the health and comfort of the community of which he is a unit. Until this is recognised by the individual himself, and by the controlling authorities, to be as applicable to air pollution as to other nuisances, the smoke difficulty will not be overcome.

THE WASTE OF FUEL.

The subject of smoke prevention admits of wider treatment than is usually accorded to it. The whole question of the combustion of coal is one of national importance, and is inevitably linked with that of smoke prevention. Not that it must be supposed for one moment that a smokeless fire is *necessarily* an economical fire; in many cases a fire may be perfectly smokeless and yet may be the cause of a great waste of heat. Still, on the other hand, a fire may easily be smokeless and efficient; in fact some of the causes of smokeless firing are also the causes of perfect combustion if not carried beyond their proper limits. *Perfect combustion is smokeless combustion.*

There is only a certain quantity of coal in the world. What that quantity is no one knows precisely, but geologists are able to form very reasonable estimates as to this amount in given districts; and it is considered, in this country at any rate, that, assuming the output of coal to go on increasing at the same rate as heretofore, the supply will be exhausted in a little over a century. This estimate is probably too short by many years, because there are limits beyond which this output cannot extend under ordinary circumstances. The limits which are imposed are the natural limits to the growth of the population and the opening up of coalfields abroad, which will tend after a time to put a restriction on the quantity of coal exported, thus leaving more for home consumption. However, there can be little reasonable doubt that the exhaustion of the supply is within sight, and it therefore behoves all users of coal to limit the amount consumed as far as possible, by making use of every possible unit of heat which is given out by the combustion of the coal, and to indulge in no cause of waste that can by any possibility be avoided. Some heat must of necessity be thrown away, but the tendency of all modern furnaces is to reduce this waste to the very smallest proportions by burning the coal in a more perfect manner. In the furnaces which are most economical the combustion is in many cases almost smokeless, and in this way smokelessness is coincident with economy under the best conditions.

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CHAPTER I.

FUELS AND COMBUSTION: THE CHEMICAL ACTIONS INVOLVED.

In reviewing the causes which contribute to the presence of smoke in the atmospheres of our towns, it is easy to divide these into three classes, as follows:—

1. Domestic fires.
2. Boiler fires used for the raising of steam.
3. Other furnaces used for industrial purposes, such as metallurgical furnaces, fires for evaporating pans in chemical works, the fires used by brewers, and many others of similar kind.

Of these, although house fires are responsible for a great deal of the smoke produced, it is the factory furnaces which are most to blame, because they individually produce far more smoke than do the smaller fires which are used in houses, the issuing of smoke from their chimneys is more easily observable, and there are other ways more definite in which the combustion in these may be improved.

At the same time it will be well to look at the question of combustion of coal in domestic fires, and to see in what directions attempts have been made at improvement, and what are the possibilities for the future.

It is held by some that the evil caused by the emission of smoke from house fires is far greater than that due to boiler furnaces. The writer does not altogether agree with this opinion, because so much depends on the relative number of house fires to mill fires, the natural features of the locality in question, and many other minor points which make it impossible to make any definite statement on the matter. At the same time a great deal of the smoke with which we are troubled in our towns is undoubtedly caused by small domestic fires. One thing that makes house fires specially unpleasant in their effects is that the chimneys from which their smoke issues are as a rule on a lower level than are mill chimneys, and there is, consequently, less general diffusion, and the smoke comes back to us at once, often in the form of large smuts. It is also considered that the smoke given off from house fires is more harmful in its nature, being more sticky, and containing a larger amount of sulphurous acid.

With very few exceptions *ordinary house fires* are of the open-grate type, at any rate in Britain. The reason for this is not far to seek. We Britons like to see the open, free combustion, with its accompaniment of glowing coke and blaze, and we have an instinctive repugnance to anything approaching a closed stove, though the combustion may be more perfect and more heat given out. We prefer to see the fire rather than to benefit by the warming of air in a rational manner, and are quite content to allow the greater proportion of the heat to be taken up the chimney and wasted, rather than adopt means whereby more of this heat could be made use of and only half as much coal burnt. The heating of a room by means of an open fire is effected almost entirely by radiation, and very little use is made of the heating of the air by conduction and convection.

In the *Galton chamber system* much heat that would otherwise be lost is recovered by allowing the air which is admitted to ventilate the room to pass through chambers placed behind or at the sides of the fire. The air thus admitted becomes heated and is allowed to pass into the room, in this way carrying back to the room much of the heat that would otherwise be lost. There is a great deal of scope for improvement in the economy of the heat given out by the fuel on open house fires, but we cannot expect much to be done in this direction until the public can be persuaded to look upon the matter in an unbiassed spirit.

The whole subject of heating and ventilation is a difficult one, and is really very little understood by those responsible for it. But any fires which have been introduced for the purpose of economising the heat are not necessarily smokeless, and very little has been done to construct an open fire which s at the same time smokeless. Two grates of this kind may be mentioned, but they have not been generally adopted. These, however, serve to show in what directions improvements must be made to effect the desired result.

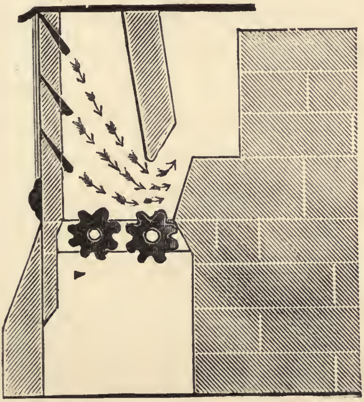

FIG. 1.—Marsh grate.

In the *Marsh grate*, of which a section is shown in Fig. 1, the principle is the same as that adopted in some boiler furnaces to be afterwards described. The coal is fed in from above, through an opening which can be closed by a door. The air for combustion passes in from the front in a sloping downward direction, through inclined firebars or louvres, as shown. This air, before it can leave the fire, is constrained by a baffle plate to pass downwards through the incandescent fuel at the bottom of the grate, from whence it passes to the chimney. The louvres are made adjustable, so that the air supply can be regulated. This form of grate is specially applicable to cooking ranges, the fire as seen through the louvres being incandescent, so that it can be used for toasting and the roasting of meat.

In the *Arnott grate*, for room fires only, the supply of coal necessary for all the time during which the fire is expected to burn, is put into the grate at the commencement of the day. The lower part of the grate is a closed box containing the coal, which burns at the top only, so that any volatile products given off from the fresh coal must pass through the incandescent zone and become thoroughly burnt. The upper part, where the burning takes place, is fronted by bars in the ordinary way. As the coal burns away, the bottom of the box is raised by a screw arrangement, and the fuel in this way pushed up. This grate is said to be quite smokeless, but suffers from the disadvantage of the difficulty in gauging the right quantity of coal to be put into the box when the fire is lighted.

The real solution of the matter with regard to house fires, both for heating and cooking, is to be found in gas fires. Though these are greatly on the increase, their adoption cannot be general until a cheaper kind of gas is supplied by the local authorities.

Of the two classes of *industrial furnaces*, those of steam boilers very much exceed the others in numbers, and it will be best to confine the discussion to these.

The fuel consumed in boiler furnaces is, in almost all cases, obtained from coal, which is either burnt direct on the boiler furnace, or volatilised, and the gas so produced burnt in the place of the coal itself. And in some few cases the gaseous fuel is obtained from the coal, but as a by-product of some special process, such as the making of coke.

Where the fuel is gaseous, however produced, the combustion is almost always free from smoke, and therefore need not be considered in any detail.

The question, therefore, becomes narrowed down to the combustion of coal in the furnaces of boilers, and, in this connection, it is necessary to bear in mind that *economy* must not be lost sight of when considering the question from the point of view of the *smoke*.

Chemical Actions Taking Place during Combustion.

In order to more fully comprehend what takes place during the process of combustion in a boiler or other furnace, the following brief summary of the needful chemical facts will be helpful.

All fuels, whether solid like coal, liquid as petroleum, or gaseous, are, chemically speaking, compound substances, made up of certain proportions of the simpler substances or elements. Coal, for instance, is a complex substance, consisting of the elements hydrogen and oxygen, which exist separately under ordinary conditions as gases; carbon, which is a solid; sulphur, nitrogen and ash. These exist in the coal in various quantities, according to its age and origin. But, in complex substances such as coal, the elementary substances first combine to form what are called compounds, in which the elements always exist in the same unvarying proportions. The smallest particle of a compound substance which can have separate existence is called a molecule, this molecule being made up of atoms of the various substances forming the compound.

This will be best made clear by the consideration of a concrete example. Take the case of the formation of water, by the combination of hydrogen and oxygen. If there are 18 pounds of water, there will be 16 pounds of oxygen and 2 pounds of hydrogen ; and the gases always combine in exactly this same ratio, which is fixed and invariable. The atomic weight of hydrogen is said to be 1, and that of oxygen 16. Each element has its own atomic weight. This atomic weight is a relative quantity, and denotes the proportion in which this element exists in a compound, or the multiple of such proportion. Thus, in the case of water, two molecules, that is, two volumes, of hydrogen combine with one molecule, that is one volume, of oxygen to form two volumes of water in the form of steam. The molecular weight of hydrogen is said to be 2, the molecule of hydrogen being the smallest particle which can exist as hydrogen ; similarly, the molecular weight of oxygen is 32, or the weight of two atoms.

The process of the combination is thus expressed :—

$$\begin{array}{ccccc} \text{(Hydrogen)} & \text{combines with} & \text{(Oxygen)} & \text{to form} & \text{(Steam)} \\ 2H & + & O & = & 2H_2O \\ \text{(2 Volumes)} & & \text{(1 Volume)} & & \text{(2 Volumes)} \\ 2 \times 2 & + & 32 & = & 2 \times 18. \end{array}$$

One molecule of water is made up of two atoms of hydrogen and one atom of oxygen, and the symbolic expression for water is H_2O. The same reasoning applies to the other combinations occurring in the combustion of fuel. In coal the principal cases are those of the combination of the hydrogen in the coal with the oxygen of the air, to form water; the formation of carbon dioxide or carbonic acid by the combination of the carbon with the oxygen ; and the incomplete combustion of the carbon, forming carbonic oxide or carbon monoxide ; and, lastly, the burning of this carbon monoxide, by taking up another atom of oxygen so as to form carbon dioxide. There is also the combustion of the sulphur in the coal so as to form sulphur dioxide (SO_2), but this is generally neglected. Coke, which is sometimes used for raising steam, is almost entirely composed of carbon and contains very little gaseous matter. The reactions which take place in the case of the combustion of oils and producer and coke-oven gases are more complex.

The following figures will be found useful :—

TABLE I.—ATOMIC AND MOLECULAR WEIGHTS.

Name of Substance.	Symbol.	Atomic weight.	Molecular weight.	Pounds in one cubic foot.	Cubic feet in one pound.
Hydrogen . .	H	1	2	0·00559	178·83
Carbon . . .	C	12	24	...	...
Oxygen . . .	O	16	32	0·08950	11·18
Nitrogen . . .	N	14	28	0·07830	12·77
Sulphur . . .	S	32	64	...	...
Water (steam) .	H_2O	...	18	...	...
Carbonic oxide .	CO	...	28	0·07830	12·77
Carbon dioxide .	CO_2	...	44	0·12300	8·13
Atmospheric air .	...	...	...	0·08073	12·39

QUANTITY OF AIR REQUIRED FOR COMBUSTION.

A molecule of the carbon dioxide formed by the complete combustion of carbon in air is made up of one atom of carbon and two atoms of oxygen (CO_2), so that in 44 pounds of the gas there are 12 of carbon and $2 \times 16 = 32$ pounds of oxygen, or, in other words, one pound of carbon requires for its combustion $\frac{32}{12} = 2·66$ pounds of oxygen.

Now, the air of the atmosphere is simply a mechanical mixture of oxygen, which combines with other substances during the process of combustion, and nitrogen gas, which is inert and simply serves to dilute the oxygen. It is in this way useful in checking a too rapid combustion of both combustibles and animal tissues, but, unfortunately, it takes up heat and carries it away to waste.

In 100 volumes of atmospheric air there are 79 volumes of nitrogen and 21 volumes of oxygen.

And as the weights of equal volumes of nitrogen and oxygen are as 14 to 16, the proportions by weight are approximately 23 to 77.

That is to say, in the air there is a percentage, by weight, of oxygen of 23, and, as one pound of carbon requires for its complete combustion 2·66 pounds of oxygen, this will be equivalent to saying that one pound of carbon requires for its complete combustion $2{\cdot}66 \times \frac{100}{23} = 11{\cdot}56$ pounds of air.

Similarly, one pound of hydrogen requires 36·6 pounds of air. The quantity of air required per pound of a fuel containing hydrogen and carbon is given by the following formula. Here H represents the fraction of a pound of hydrogen contained in one pound of the fuel; C represents the same value for the carbon in the fuel, and the O is for the oxygen in the fuel itself. These values of H, C, and O must be obtained by means of a chemical analysis of the coal. Then the number of pounds of air required, A, is given by

$$A = 11{\cdot}56\,C + 36\left(H - \frac{O}{8}\right).$$

Here it will be seen that one-eighth the weight of oxygen in the fuel, representing its equivalent weight of hydrogen, is subtracted from the hydrogen. There is some divergence of opinion as to how this combined oxygen should be dealt with, but although dissociation of the hydrogen and oxygen takes place at very high temperatures, recombination may be expected to take place at the lower temperatures found in the further parts of the boiler flues, so that all the hydrogen will take up its proper amount of oxygen, and it does not matter whether this is free or combined. We may therefore assume the above formula to be approximately correct for combustion in boiler furnaces. It is often used as follows:—

$$A = 12\,C + 36\left(H - \frac{O}{8}\right).$$

The different kinds of coal used vary very much in their smoke-producing capacity. For instance, the anthracite coal of Wales is very nearly smokeless, even when burned without any special means being adopted for the purpose of preventing the emission of smoke. On the other hand, the coal known as the "Wigan four-foot seam" contains a large amount of volatile matter, and is very smoky in its combustion. The coals which are used for the production of illuminating gas contain an even greater amount of volatile matter. The coke which is left after the distillation of the gaseous matters from a coal is practically all carbon, and burns with a total absence of smoke.

The precise analysis of the several kinds of coal used are given in the following table. Only the constituents with which we are particularly concerned, that is, the hydrogen, carbon and oxygen, are mentioned, the quantity of sulphur being small and quite negligible as a heat-giving combustible. The actual percentage of sulphur varies from 0·75 to 1·50 per cent.

TABLE II.—COMPOSITION OF COAL AND COKE.

Kind of Fuel.	C	H	O	A	Smoke-giving qualities.
Coke (good) . .	0·94	...	...	11·28	No smoke.
Coal, anthracite .	0·915	0·035	0·026	12·13	Practically no smoke.
,, dry bituminous	0·87	0·05	0·04	12·06	Hardly any smoke.
,, caking . .	0·85	0·05	0·06	11·73	Very little.
,, cannel . .	0·84	0·06	0·08	11·88	Considerable quantity.
,, dry long flaming	0·77	0·05	0·15	10·32	Very smoky.
,, lignite . .	0·70	0·05	0·20	9·3	Very smoky.

In this table are not included the liquid and gaseous fuels, nor such occasional fuels as wood and peat. C, H, and O represent the fractions of a pound of the combustible referred to in one pound of the fuel. The letter A refers to the number of pounds of air required for the perfect combustion of one pound of the fuel, as obtained by means of the formula given above.

The quality of each coal as regards its smoke-producing properties is given in the last column. Of course it must be understood that these are only average values, and must not be taken as absolute, especially as regards the coke, of which there are many varieties.

TABLE III.—COMPOSITION OF OTHER FUELS (SOLID AND LIQUID).

Kind of Fuel.	C	H	O	Ash.
Charcoal from wood	0·93	...	...	0·075
Paraffin oil	0·85	0·15	...	...
Average petroleum	0·84	0·11	0·05	...
Average dry peat	0·57	0·06	0·32	0·05
Average dry wood	0·50	0·06	0·42	0·02
Sawdust, dry	0·41	0·04	0·53	0·02
Dry straw	0·36	0·05	0·54	0·05
Tar refuse	0·82	0·10	0·07	...

It will be noticed (Table II.), that the liability to give off black smoke increases as there is more hydrogen and oxygen, and diminishes as the proportion of carbon in the fuel increases.

From charcoal and coke, and to a lesser extent anthracite coal, which consist almost entirely of carbon, there is practically no smoke produced under any circumstances. The liquid hydrocarbons are very smoky unless the air supply is carefully attended to. The same is true to a smaller extent in the case of wood and peat, although such smoke as is produced is not so objectionable as that given off from coal. The more gassy a coal is, that is, the more hydrogen and oxygen it contains, the more liable it is to smoke, and, therefore, all the more care is required in the adjustment of the air supply.

A table containing the proportions of the constituents of most of the gaseous fuels now in use, with the quantity of air required, in cubic feet per cubic foot of the fuel, is given on p. 96.

The gaseous fuels, that is to say, the gases containing high percentages of carbonic oxide and low percentages of hydrogen, are smokeless.

COMBUSTION OF COAL IN BOILER FURNACES.

The chief constituents of coal, so far as heat-giving properties are concerned, are, as we have seen, hydrogen, carbon and sulphur. Of these the sulphur only occurs in small quantities, and has a low heat-giving value, so that it is neglected in comparison with the other constituents. During the process of combustion the hydrogen of the coal combines with the oxygen of the air to form steam, and heat is given out in the process; the carbon also combines with the oxygen to form carbon dioxide or carbonic acid (CO_2) when the air supply is plentiful and complete combustion takes place; but with an insufficient air supply only partial combustion takes place, and carbonic oxide (CO) is formed, with the generation of a much smaller quantity of heat. It is therefore important that, irrespective of any other considerations, the carbon in the fuel should be burnt so as to produce CO_2, and not CO, the production of the latter being necessarily accompanied by a distinct loss of heat that would otherwise have been evolved.

What actually takes place when coal is burnt on a boiler furnace is not easy to define in a few words. The process of the combustion of coal is a very complex one, and depends to a great extent on the external circumstances accompanying the combustion. When firing takes place, that is, when a fresh supply of coal is thrown on the fire, the fire generally consists of a layer of fuel more or less completely incandescent, this being the carbon of the coal in the form of coke.

On the new supply of coal being placed upon this glowing mass of fuel, the heat of the latter causes the release of the gaseous constituents of the coal, the hydrocarbons are driven off, and burn above the fire with luminous flames. These gases consist of combinations of the hydrogen in the coal with some of the carbon, which go to make up those hydrocarbons which form a large part of illuminating coal gas. Just as heat is absorbed during the process of the generation of steam from water, so, when the gases are driven off from the coal, we have simply a process of evaporation, and heat is consequently absorbed during the process, and a cooling of the furnace is the result. A high temperature is necessary, as otherwise the carbon and hydrogen will not combine with the oxygen of the air.

If the temperature of the furnace is sufficiently high and the air supply ample the hydrocarbon gases will burn above the furnace with a heat-giving flame, steam and carbon dioxide being formed. If these two conditions are lacking, the result will be the formation of smoke. This is a most important point to be noted in connection with smoke production, and will be referred to later more in detail.

The combustion can then be divided into two stages—the volatilisation and combustion of the hydrocarbons, and, secondly, the combustion of the remaining carbon. The carbon may be completely burnt to CO_2, or only partially to CO. Most of the air which is used for the combustion of the carbon in this second stage is that which is allowed to pass upward between the furnace bars. If the air supply is ample, then the carbon will be completely burnt to CO_2, which will pass away from the top of the fire to the flues and thence to the chimney. If the air supply from below is insufficient, the carbon will only combine to form CO, which will appear at the top of the fire, and if there is a sufficient supply of air there, the CO will burn. The flame of CO is readily distinguished by its violet-blue tint. If the conditions necessary for the proper combustion of the CO are absent, then the gas will pass off as CO, and will result in a corresponding loss of heat. The actual interchanges which take place between the carbon and the oxygen are not very clearly understood, and it is held by some authorities that CO_2 is formed first, and takes up a further quantity of carbon as it passes over or through the incandescent fuel, and in this way the CO is formed. This, however, does not greatly matter so far as the present argument is concerned, the main point being that with a sufficient air supply CO_2 is formed, which means that the carbon is perfectly consumed, and that with an insufficient air supply CO will be produced with a corresponding loss of heat and boiler efficiency.

FORMATION OF SMOKE.

The formation or non-formation of smoke is a matter of air supply and temperature. This much may be taken as certain, although the details of the various processes are not yet clearly determined. The formation of smoke occurs during the volatilisation of the hydrocarbon gases. As these come off from the coal, if the air supply is sufficient and at the same time the surrounding temperature is high enough to allow of combustion taking place, the gases will burn with a bright flame, steam and carbon dioxide being formed in the process. If, however, the air supply is deficient, or, the air being plentiful, the flames penetrate to portions of the flues which are below the necessary temperature, a recondensation of the gases takes place, and the carbon becomes separated out in a finely divided condition and smoke is formed. Another reason given for the formation of smoke in some cases is that the high temperature of the furnace causes a dissociation of the constituents of the hydrocarbons, which, if the supply of oxygen is deficient, results in unburnt hydrogen and unconsumed carbon in the form of smoke. If the air supply is ample when this takes place the hydrogen and the carbon will be burnt and no smoke result. The formation of smoke caused by an insufficient air supply is seen in the case of an oil lamp without a chimney. If the wick is turned up a little too high, the natural air supply is not sufficient to maintain perfect combustion, but if now a glass chimney be placed on the lamp, an induced draught will be produced, more oxygen will reach the flame, and clear and smokeless combustion will result.

Some of the finely divided carbon forming the soot probably comes off from the coal direct without being first combined with the hydrogen. This point is, however, somewhat obscure, and in the present state of our knowledge on the subject no definite opinion can be expressed.

SATISFACTORY COMBUSTION IN BOILER FURNACES.

In order that the combustion of the fuel in a boiler furnace may be perfectly satisfactory, from the point of view of the owner and that of the outside public, the combustion must be both economical and smokeless. These two conditions are not necessarily co-existent. A furnace may be highly economical, regarding the economy from all points of view, and at the same time may be periodically sending forth a quantity of unburnt carbon in the form of smoke; or a chimney may be almost perfectly smokeless, and, at the same time, be working in a very wasteful manner. It must not be supposed that these two conditions are necessarily opposed to one another, but in some cases they may be, and it is necessary to be careful in discriminating between smokelessness and economy.

The principal conditions which affect these two are as follows:—

1. The presence of smoke in the gases escaping from a boiler flue is in most cases due to an insufficient air supply either in the neighbourhood of the fire door and above the fuel or at the back of the furnace near the bridge, or to partially burnt gases coming

in contact with the cooling surfaces provided by the boiler plates next the water.

2. Economical combustion may be interfered with, to a small extent only, by the amount of carbon carried away as smoke and by a deposit of carbon on the flue plates, which interferes with the proper transmission of heat through the plates. The chief source of loss of economy in the combustion of the coal is due to a too liberal air supply, which, besides the excess oxygen present, contains much inert nitrogen, which takes up heat, and carries it away up the chimney to waste. A too small air supply results in the formation of a quantity of CO, and the carbon burnt in producing it is only partially consumed, and yields only rather less than one-third the heat that ought to be evolved in its complete combustion. Great care is therefore necessary in arranging the air supply so as to give the maximum economy in the combustion, combined with a smokeless chimney. Besides serving as a carrier of heat to waste, the excess air has a cooling effect on the flues.

If it is important that the air supply should be carefully regulated as to quantity, so also the time of admission should be attended to. After firing the maximum quantity of oxygen is required for several minutes, until the whole of the hydrocarbons have been driven off and consumed; after this time the supply should be much reduced. An excessive supply of air after the hydrocarbons have been driven off is not needed, and is a source of waste. During the gasification period, or that immediately after firing, air should be supplied not only underneath and over the bars, but also at or near the bridge, so as to completely consume the hydrocarbon gases.

Effect of Air Supply on Economy and Smoke.

It has been said that the presence of, or freedom from smoke in a boiler depends, more than upon anything else, on the quantity of air supplied to the furnace, the time at which this supply is admitted, and the place of admission, that is, whether the air is allowed to pass into the furnace above the fire bars, below them, or both above and below at the same time.

But not only is the smoke affected by the air supply; the economical working of the boiler depends to a great extent on this also. From the figures given in Table III. above, it will be seen that the number of pounds of air required per pound of coal is somewhere in the neighbourhood of 12, and does not vary greatly from this figure. An average value for the minimum weight of air per pound of coal may be taken as 11·5 pounds. This quantity is only that required under the most favourable conditions, that is, when every particle of the oxygen of the air supplied is completely consumed, and there is no waste oxygen carrying heat away. These conditions are not possible of attainment in ordinary boiler furnaces, as it is not practicable to bring all the oxygen intimately in contact with the burning fuel so that it may be used. Perhaps the nearest approach to this ideal condition is to be found in the case of powdered fuel combustion. Here the coal is reduced to an impalpable powder and is floated into the furnace, each particle surrounded by its own necessary quantity of air. In this form of combustion there is very little excess air required, and the loss of economy from this cause is much reduced.

But when the fuel is burned in lumps, though possibly these may be small, it is not possible to avoid the admission of a considerable excess of air.

If the air supply is deficient, either in the general supply or the quantity admitted to some important point of the furnace, the carbon does not take up its proper amount of oxygen, and carbon monoxide is formed instead of carbon dioxide. One pound of carbon, if completely burned to CO_2, gives out by its combustion about 14,500 heat units, whereas if partially burned, to CO, the heat yielded is only 4,500 heat units. It is therefore obvious that for every pound of carbon burned to CO instead of to CO_2 there is a loss of heat equal to about 10,000 heat units. For this reason alone it is obviously necessary for economy that the carbon be fully burnt.

This carbon may be the free carbon in the incandescent fuel left after the hydrocarbons have been driven off, or it may be combined carbon in the gases. If the former, the CO goes off as a totally invisible gas, and if the latter, the imperfect combustion may be accompanied by the evolution of smoke. In either case the remedy is more air, and consequently more oxygen.

The problem with which the owners of boilers are confronted is not altogether a simple one, for if the air supply is deficient, CO is formed in place of CO_2, and a consequent waste of heat takes place, and this may be accompanied by the formation of smoke; whereas if too much air is admitted to the furnace, there is again a loss resulting from the excess oxygen and nitrogen taking up heat and carrying it away from the boiler. There is a point where one loss ends and the other begins as the air supply is increased, and in order to obtain the most economical results with freedom from smoke, this point must be found. There is the further question as to how far it is allowable to permit a large excess of air in order to force the boiler, and so get a greater total evaporation from a given boiler, but that point need not be considered at present.

The best indication of the quantity of air being used per pound of coal is that given by an analysis of the gases coming away from the furnace. This is not difficult to obtain, samples of the gases being collected at suitable places in the flues, and the analysis made by means of one of the many forms of rough apparatus used for the purpose.

On analysing the products of combustion, they will be found to consist of the following constituent gases:—

Carbon dioxide, or carbonic acid gas (CO_2), from the carbon of the coal and the oxygen of the atmosphere. There is found to be 17 to 5 per cent. of this gas present. These are extreme figures, the more usual ones being from 12 to 7 per cent.

Free Oxygen (O). There is usually from 12 to 4 per cent. of this gas.

Carbon monoxide, or carbonic oxide (CO). From 2·5 per cent. to none. In very many boilers, working fairly economically, the quantity of this gas which can be detected by the usual means is *nil*.

Unburnt Hydrocarbons. These are small in quantity and not found by the ordinary analysis, but they often exist and must be a source of loss.

The last gas in the flue gases is *nitrogen* (N), which is found by difference, that is to say, all the others are found directly, and the sum total of these subtracted from 100, and the remainder assumed to consist wholly of nitrogen. Usually there is about 80 per cent. of this gas present.

It is clear, then, that any excess of air in the flue gases results in heat being carried away to the chimney and so wasted; and, on the other hand, a deficiency in the air supply is the cause of a loss on account of the fuel being incompletely burnt and the escape of the carbon monoxide without being burnt.

It is possible to estimate the *actual* amount of both these losses from an analysis of the flue gases. Of course the quantity of excess air could be found by measuring the volume of air passing into the furnace, but this is not very often done, it being found much more convenient to analyse the escaping gases and estimate the quantity of air in that way.

This estimation is necessarily approximate, but the results are quite near enough to the truth for the purposes for which they are required. Without going into details it will be sufficient to quote the following formulæ as useful in making the above mentioned determinations :—

1. The amount of air is given by Dr. Bunté's formula, which is—

$$R = \frac{18{\cdot}9}{CO_2},$$

where R is the ratio of the air actually used to the minimum quantity actually required for complete combustion of one pound of the coal, and CO_2 is the percentage by volume of the carbon dioxide in the flue gases, as found by analysis. Or it may be convenient to have it in the form—

$$E = \left(\frac{18{\cdot}9}{CO_2} - 1\right) 100,$$

where E is the percentage of excess air actually present. Or, again—

$$a = 11{\cdot}5 \ \frac{18{\cdot}9}{CO_2}$$

will give a, which is the actual quantity of air used per pound of fuel.

The percentage loss of heat, that is, the percentage which the heat lost forms of the heat given out by the fuel, is given by the German formula—

$$L = \frac{T - t}{CO_2} \ 0{\cdot}65,$$

in which L is the percentage loss of heat, t is the initial temperature of the air entering the furnace, T is the final temperature of the gases as they leave the flue for the chimney, and CO_2 the percentage of carbon dioxide in the flue gases *by weight*, and not, as before, by volume.

Where the percentage of CO_2 is known by volume, as is generally the case, the corresponding percentage by weight may be obtained roughly by the following :—

$$CO_2 \text{ (by weight)} = w = \frac{CO_2 \text{ (vol.)}}{65 - 0{\cdot}8CO_2} 100.$$

The third formula gives the loss of heat, expressed as a percentage as before, due to the formation of CO, and is given by—

$$l = 2{\cdot}2CO,$$

where l is the percentage loss of heat and CO is the percentage of carbon monoxide in the flue gases by volume.

In the following table are given the excess air per cent. for different quantities of CO_2 in the flue gases, and also the pounds of air per pound of fuel :—

TABLE IV.—TABLE OF EXCESS AIR IN FLUE GASES.

Per cent. CO_2 in the flue gases (by vol.).	Per cent. excess air in flues.	Pounds of air per pound of coal (average).
2	845	1,085
4	373	545
6	215	362
8	136	27
10	89	22
12	58	19
14	35	16
16	18	14

On the accompanying diagram (Fig. 2) are drawn two curves derived from the two last formulæ, and giving respectively the loss of heat due to excess air, as shown by various percentages of CO_2, in the flue gases, and the loss of heat caused by shortness of oxygen, as shown by the amount of CO, in the gases.

The most striking fact revealed by the diagram is how enormously the loss of heat increases when the quantity of CO_2 gets much below 5 per cent. It is to be observed that the two curves are to be considered independently, and not as if related in any way, although, of course, there is a point when the decrease of the air supply, although reducing the loss in its own direction, is conducive to the generation of CO, and the gain in heat by reducing the excess air is balanced and exceeded by the loss caused by the incomplete combustion of the coal.

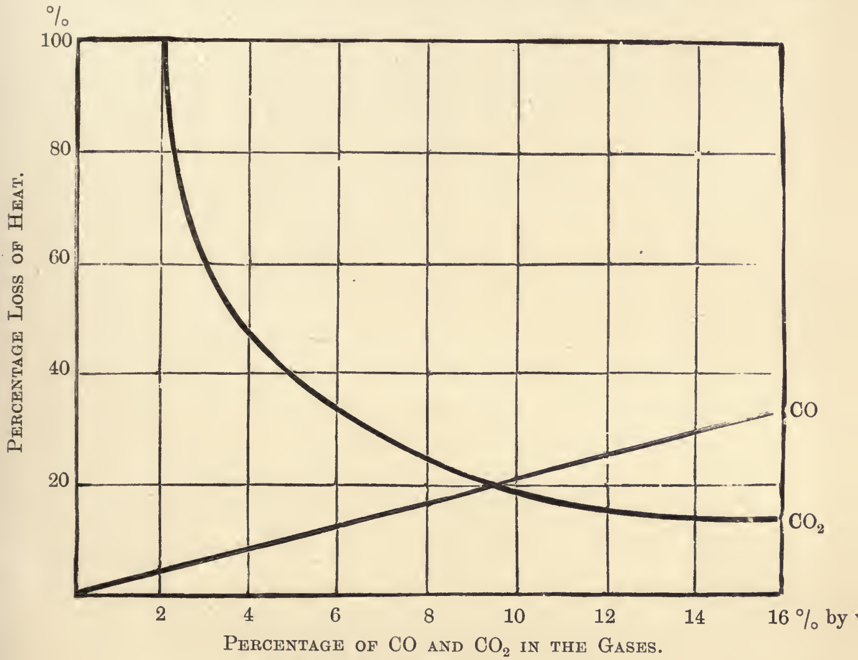

Fig. 2.—Diagram showing waste of heat.

CHAPTER II.

HAND-FIRING IN BOILER FURNACES.

FROM what has been said in the last chapter, a general indication of what may be expected to occur during the combustion of fuel on the fire bars of a boiler furnace has been given. It will now be possible to make a more detailed survey of this part of the subject, and to examine some of the most commonly used types of fire grates for boilers.

COMBUSTION IN ORDINARY HAND-FIRED BOILERS.

In Fig. 3 will be seen a section of a typical grate such as is used in an internally fired boiler. The fuel, which in this case must be solid coal, coke, or briquettes in large or small lumps, is thrown by hand on to the fire bars as shown in the sketch, and there burns, giving out heat during the combustion, the greater part of which should be transmitted to the water, the remainder being lost. Next to the fire door, through which the fuel is fed, is a flat plate of cast-iron called the dead plate, about one foot in depth, measuring from the boiler front. Next come the fire bars, on which the actual combustion takes place. These are usually of cast-iron, arranged in two or three lengths. In very small boilers one length is found to be sufficient. In most cases the bars run longitudinally with the length of the boiler, and are placed level with each other with a small space between them. The width of the openings between the bars should be made to depend on the kind of fuel used. Where the fuel is in large pieces the spaces may be greater, but in the case of very small slack the bars must be placed very close together so as not to allow any perceptible quantity of the coal to fall between the bars into the ashpit along with the ash. Occasionally the bars are hollow, so as to allow of air passing through them to the back of the fire, but the objection to these is that they are liable to be burnt out by the heat of the furnace, and time and labour are wasted in replacing the damaged bars. Where air is introduced under pressure beneath the bars, either by means of a fan or a steam jet, small slack is generally used, and the bars are placed very near together. This spacing of the fire bars is a really important point, and should be carefully considered by a competent person, with due regard to the kind of coal that is to be used, so as to allow no fuel to pass through, and at the same time to permit of sufficient air passing through the bars to effect complete combustion, so far as the air passing between the bars can do this.

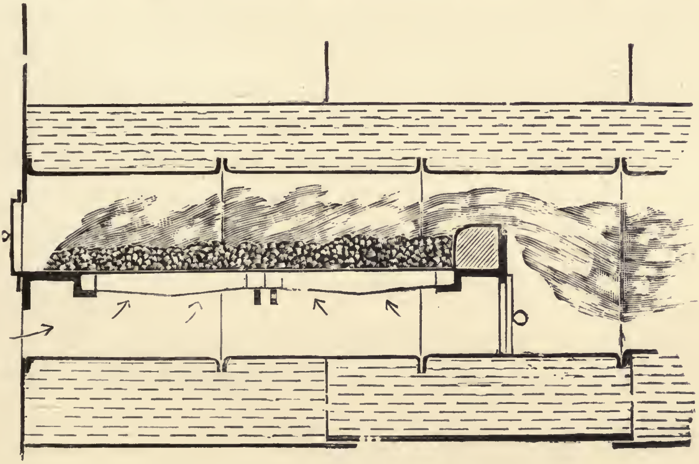

FIG. 3.—Section of typical Boiler Furnace.

Other arrangements of the fire bars are in vogue in some cases. For instance, they may be arranged in steps instead of on the level. In both hand-fired boilers and mechanical

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stokers they are sometimes made movable, and in some grates they are arranged in two layers, one above the other.

At the back of the furnace there is provided a "bridge," which is a firebrick barrier extending rather more than half way up the flue depth, its functions being to prevent any of the fuel from dropping over the back end of the bars and falling on the lower plates of the flue, and to deflect the hot gases upwards. The bridge, or the cast-iron frame on which it rests, ought to reach to the bottom of the flue and entirely close up the opening, so that no air can get to the back of the bridge, except that which has come over with the gases of combustion. In some cases an air valve in the bridge casting is provided, which can be used both for the purpose of cleaning the flue dust and ash out from behind the bridge, and also for admitting an additional supply of air behind the bridge in order to assist combustion just after firing, when the greatest amount of excess air is required.

METHODS OF HAND-FIRING.

Different systems of feeding the fuel on to the grate bars are used in different districts and by different firemen. These are:—

Uniform Firing, where the fireman endeavours to preserve a layer of equal thickness over the bars, care being taken to fill up any parts that show signs of getting thin. This uniform firing may result in a thin or thick fire, this generally depending on the kind of fuel used.

Side Firing, in which the fresh fuel is fed alternately first on one side of the fire and then on the other. This method is very effective in preventing an excessive amount of smoke.

Coking Firing, in which the fresh fuel is placed on or near the dead plate, and gradually pushed forward as combustion proceeds. By this means the hydrocarbons from the green fuel pass over the partially consumed incandescent carbon at the back.

This is important to note, because it is the plan upon which the coking mechanical stokers work.

In most cases where the boiler has two flues their furnaces are fired alternately, so that when one is in a state of incandescence the other is giving off its hydrocarbons, and the combustion of the latter is assisted by the high temperature maintained in the gases from the other furnace.

Whatever kind of firing is in use, one important point should always be kept in view, namely, that at no point on the surface of the bars is the fuel to be allowed to get so thin that air can pass upwards between the bars without passing through the fuel. There should be no bare places.

In many Lancashire boilers the fire doors are provided with air valves, or adjustable openings, which can be opened immediately after firing, when the most air is wanted. Where such valves are not provided, it is customary to leave the doors themselves ajar for two, three or four minutes after a new supply of fuel has been placed on the fire. This supply of an additional amount of air after firing must of necessity be left to the discretion of the fireman, and the behaviour of a furnace, as regards smoke, largely depends on whether the fireman uses a fair amount of intelligence in adjusting his air supply, or whether he will not take the trouble to look after it.

Air Leakages.

The boiler must be efficient as well as smokeless, and nothing tends to lower the economy more than an injudicious air supply or the leakage of air into the passages along which the flue gases pass on their way to the chimney. This air leakage may occur in several places. These are: below the front of the boiler into the bottom flue, below the fire bridge into the bottom flue, through the top covering at the back of the boiler, into the side flues between the boiler shell and where the flue cover tiles touch it, and through crevices in the brickwork generally. These are shown in the accompanying Fig. 4. A quantity of air leaking into the flues in this way tends to cool the gases and lower the amount of heat transmitted through the plates to the water. The amount of heat transmitted through a plate depends in a great measure on the difference in temperature between the gases and the water, so that, the water temperature being constant, the higher that of the flue gases, the greater amount of heat that will pass through, and the more will be utilised. The chimney draught also depends upon the temperature of the gases entering it, and therefore it is important to avoid doing anything that will affect the draught.

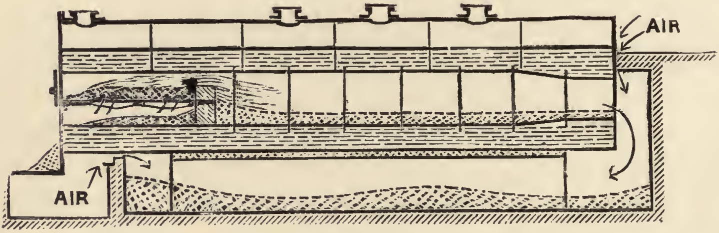


Fig. 4.—Showing air leakages in a Lancashire Boiler.

The best indication of the quantity of excess air present in the flue gases is that given by an analysis of the gases, and a determination of the quantity of CO_2 present. If this is very low it will be evident that something is wrong, and a fuller and more detailed examination ought to be made of the brickwork of the flues and all joints, and if any leakages are located these ought at once to be filled up and an analysis of the gases again made.

Care should also be taken that the flue passages are clean, as the draught and the passage of the gases may be very much interfered with by any accumulation of flue dust and ashes.

The above may seem small points, but they all tend to lower the efficiency of the boiler.

The Econometer.

This instrument is intended to give a fairly exact determination of the amount of CO_2 in the flue gases by means of one direct reading at any moment, and does not require any manipulation whatever. It consists essentially of a chemical balance, at one end of whose arm is suspended a glass globe filled with rarefied air. This serves to balance the vessel at the other end of the arm, which contains the sample of flue gas, whose percentage of CO_2 is to be determined. This weighing vessel is simply a pear-shaped globe, closed at the top, and opening by way of a long neck at its lower extremity. Through this open neck the flue gases are led through a pipe which reaches nearly to the top of the weighing vessel, but does not touch it at any point. The gases are drawn from the flue in a constant stream, which is made to flow through a pipe by means of an automatic aspirator, worked by the chimney draught. The gases so leaving the flues enter and fill the weighing vessel, from which they are led away back to the flues by way of the space between the bottle neck and the induction pipe and a second pipe. The weighing vessel is thus at all times filled with flue gases containing a certain amount of CO_2. A long pointer attached to the beam, and traversing a scale fixed to the bottom of the pillar which supports the balance, is arranged so that it stands at the zero of the scale when there is no CO_2 in the gas. As, however, CO_2 is 50 per cent. heavier than the air and other gases in the flues the more CO_2 there is in the sample which is being weighed, the further will the weighing globe be depressed, and the further will the pointer move from its zero along the graduated scale. The instrument is so calibrated by the makers that the numbers of the divisions of the scale correspond to percentages of CO_2 in the flue gases. In this way the percentage of CO_2 is given at any moment during which the furnace is working by a simple process of inspection. No attention is required beyond occasionally checking the zero of the scale and being sure that the passages are clean and free from flue dust and smoke.

By having a table showing the excess air and the percentage loss corresponding to any percentage of CO_2 the person who has charge of the boiler can at any moment form a very correct idea of the state of his furnace as regards economy.

Length of Grate.

It is also to be noted that the grate of a boiler should not be longer than can be managed comfortably, so as to have the whole of the bars covered at all times. Where a certain amount of fuel has to be burned in a certain time, it is better to have the grate short, and the fire fairly thick, than to have an excessively long grate with a very thin fire.

Air Supply at Fire Door.

A great deal may be done to prevent smoke being emitted by careful attention to an auxiliary air supply above the fire after stoking. If fresh coal is placed on the fire, especially if it is spread uniformly over the fire, and the fire door at once closed, it is pretty certain that volumes of dense smoke will be emitted for some minutes; the time during which this takes place depending on the draught, the quantity of fuel supplied, and upon the temperature of the furnace. When smoke is being given off in this way, if the fire door is opened ever so little—say, two inches—it will be noticed that the smoke diminishes in quantity and intensity almost at once, although in some cases the effect is less marked than in others.

AUXILIARY AIR SUPPLY ABOVE THE FIRE DOOR.

A plan which has been largely adopted for giving an auxiliary air supply is to provide some means of sending in a current of air above the door after stoking. If the chimney draught is exceptionally good it may be found sufficient to simply provide an opening at or above the door at the proper time, and the air will be drawn in by the force of the draught, and smokeless combustion effected.

But where the draught is not so good it is necessary to send the air in by some forcible means. The simplest way of doing this is to make use of a small jet of high-pressure steam from the boiler. This may be introduced through a pipe having an orifice about one-eighth of an inch in diameter and pointing downwards towards the bridge of the furnace. The jet is turned on while stoking takes place and the door is slightly open to allow of the admission of the requisite air. This is the plan adopted in the Whittle type of smoke preventer.

Or an opening may be made in the furnace front just above the door and the steam jet introduced through this. When the steam is turned on, air is drawn in with the steam and plays upon the top of the fire. The air opening should be provided with a door, so as not to admit any air between the firings and after the hydrocarbons have been burnt.

Another way in which the auxiliary air supply is admitted above the fuel is by means of a dead plate, which lifts and allows the air to pass inwards underneath the fire door and traversing the upper surface of the fuel as it is drawn along the flues by the draught. This is the plan adopted by Messrs. Meldrum, and is found to be very effective in diminishing the amount of smoke emitted.

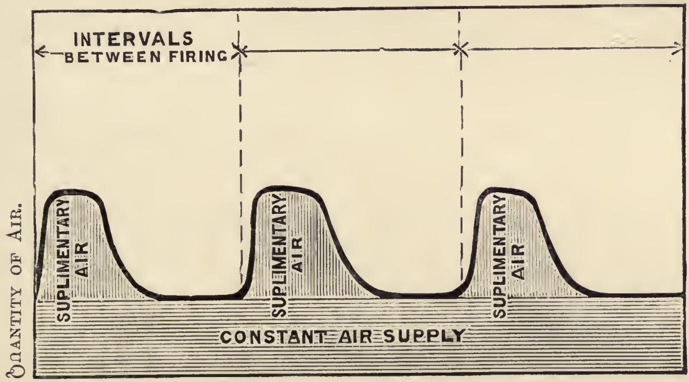
AUXILIARY AIR SUPPLY AT THE BRIDGE.

By having a split bridge, that is, a bridge with a vertical passage in it communicating with the space beneath the fire bars, an additional amount of air can be given to the gases when they reach the bridge, and require this extra supply in order to complete combustion. This arrangement is good for preventing smoke, if only it is properly used and is applied to a case for which it is suitable.

In some so-called smoke preventers air is taken to the bridge through pipes traversing the steam space or the flue, the idea being to heat the air before it reaches the gases. If the air were to be heated by being passed through the hot gases *after* they had left the boiler the plan would have something to recommend it. As it is, it is simply a case of robbing Peter to pay Paul, and taking heat out of the boiler to give it to the flue gases.

DEFECTS OF CONTINUOUS AIR SUPPLY.

In none of the cases of auxiliary air supply must the supply be continuous. This is an axiom which should never be forgotten. An auxiliary air supply is an excellent thing, both for the diminution of smoke and for the economical working of the boiler, if it is judiciously applied. The combustion which takes place in all hand-fired boilers is an intermittent process, and the air supply to be perfect must be intermittent also. In the accompanying Fig. 5 is shown a curve representing the fluctuating nature of a properly apportioned air supply. In the first place, a continuous supply is needed under the bars to burn the fixed carbon in the fuel, and also a small continuous supply above the fire to prevent the formation of unconsumed CO; but for the purpose of burning the hydrocarbons the supply must be intermittent as shown on the diagram. When stoking begins this auxiliary supply must begin at the same time, and gradually increase to a maximum when all the fuel has been put upon the fire. This maximum air supply must continue for a few minutes, and then gradually diminish to nothing, where it remains until the next firing takes place. The precise amount of air required, and the time during which it is required, can only be ascertained by trial, much depending upon the chimney draught, thickness of the fires, and so forth.



TIME.

FIG. 5.—Diagram of air supply to boiler furnace.

In hand-fired boilers the doors for admitting the auxiliary air supply are usually worked by hand, and are, consequently, under the control of the fireman, as are also the steam jets used for inducing the air currents. When no special smoke appliances beyond those that have been mentioned are attached to the boiler, the absence of smoke in the firing depends on the stoker, and he should be fully instructed as to what to do; and, if he is an intelligent and painstaking man, he will be able to keep the smoke down without loss of economy in the working of the boiler. If, as sometimes happens, the air valves and the steam jets are left open during the whole time the boiler is working, great loss of heat will ensue, and much steam will be wasted; on the other hand, if these be wholly neglected, there will in all probability be a great emission of smoke.

What has just been said applies equally well to other forms of boilers in which the ordinary type of grate is used, such as Cornish, egg-end, tubular and, to some extent, to tubulous or water-tube boilers also. In the last mentioned there is sometimes an air door under the bridge for the purpose of admitting air to the space beyond the first wall.

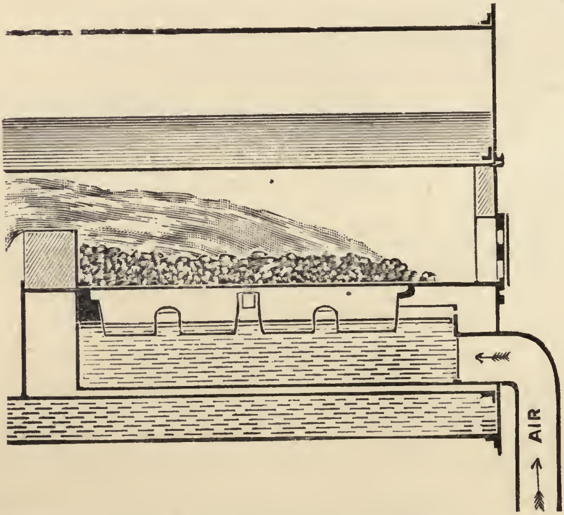


Fig. 6.—Section of Perret Grate.

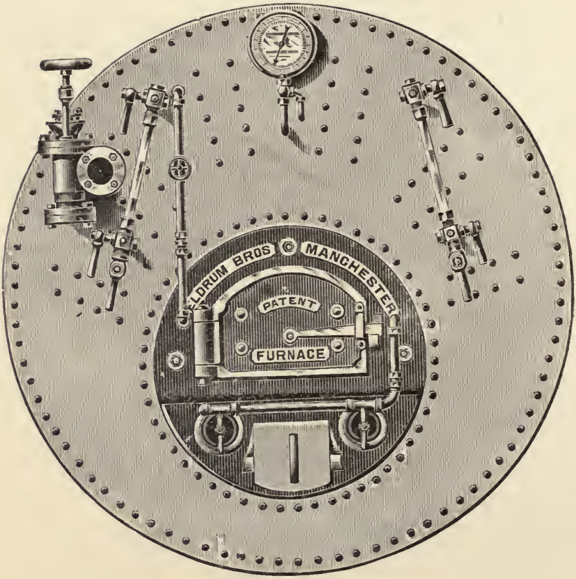
Special Grates for Hand Firing.

The Perret Grate (Fig. 6).—This grate, which is largely used on the Continent, and to some extent in this country, is designed for the purpose of burning very small coal or coke breeze. The bars are about $\frac{5}{8}$ of an inch broad and 10 inches deep, the lower edges resting in a shallow trough of water. This water keeps the bars cool and helps a little in the combustion. The bars are placed very near to one another, there being only about $\frac{1}{16}$ of an inch between them. The air is forced into the space below the bars by means of a small fan. This grate is said to yield very satisfactory results.

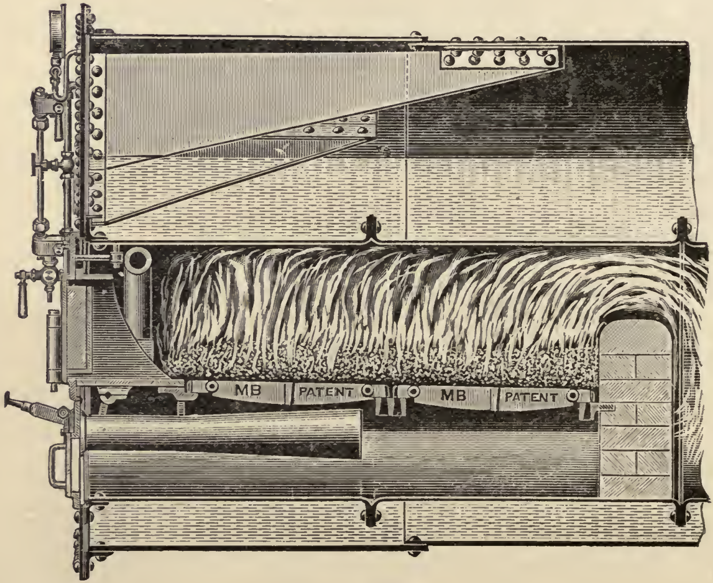
The Meldrum Furnace.

This is a largely used form of grate, in which the air is forced up between the bars, which are placed very near together for the purpose of burning small coal. There are several others worked on much the same lines. In the ordinary form of Meldrum furnace the ashpit is closed both at the back and front, and the air is introduced through a trumpet-shaped cast-iron tube, in the centre of which is a pipe conveying steam from the steam space of the boiler. Special fire bars are used, placed very near to one another, as in the Perret furnace. By this arrangement, small, cheap coal can be burnt, and a much greater evaporation obtained than in the case of ordinary draught. Another advantage of this form of forced draught is that a high temperature of combustion can be maintained, and, by this means, fuels of much lower grade, such as could not be used in an ordinary furnace, as refuse coal dust, coke, breeze and sawdust, can be made use of for the purpose of raising steam. The pressure of air maintained in the ashpit is not great, but is sufficient to force the air through bars and through the fuel.

The steam for the jet is superheated by being taken through an arched pipe placed in front of the furnace, just inside. Where the fuel is likely to produce smoke a valve dead-plate is attached, and this can be opened by hand after firing and closed again when the volatilisation period is complete. In some cases, again, where the smoke is difficult to



Front view.



Sectional View.

Fig. 7.—Meldrum Furnace.

deal with, a jet of steam is applied above the door, thus inducing a current of air on the top of the fire. In other cases a supplementary air supply is introduced through the bridge.

A sectional view of the Meldrum furnace as applied to one of the flues of a Lancashire boiler is shown in Fig. 7, accompanied also by the front view of the boiler. It will be seen that there are two blowers for the one furnace. The steam for working these is brought from the steam space of the boiler, through the arched pipe, which acts as a superheater, and is shown in section just behind the fire door, and is led into the blower tube through the cross pipe as shown. In the particular view shown there is a valve dead-plate for the admission of supplementary air above the fire; this is opened and shut by means of the handle shown projecting from the boiler front below the fire door. The internal arrangements of this furnace front are shown more clearly on the photograph in Fig. 8. Here the valve dead-plate is shown open. In the

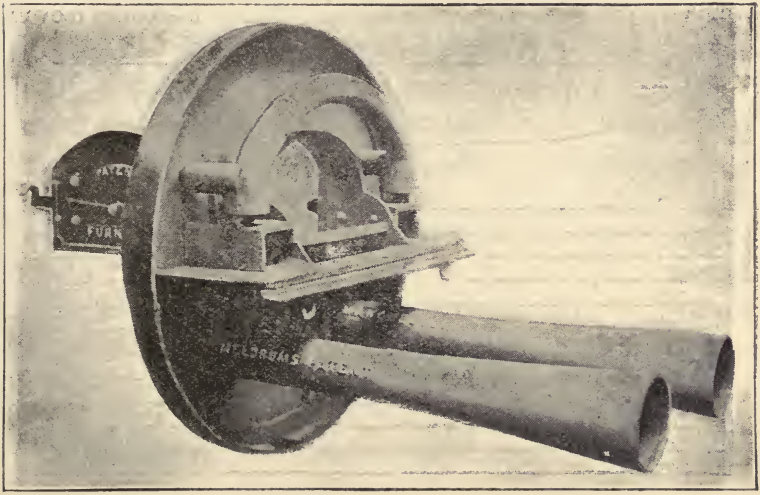


FIG. 8.—Inside view of Meldrum Furnace.

next illustration (Fig. 9) will be seen a plan view of the Meldrum grate bars. These are cast with lugs, so that they interlock when placed in position. The space between these bars is somewhere about $\frac{1}{16}$ of an inch. One of the objections to these steam jet blowers is that they give rise to an unpleasant noise, and, with the object of preventing this, Messrs. Meldrum have designed their "Silent Blower," in which the air and steam are led to the furnace by way of an underground conduit. In some cases the conduit draws its air from a room which requires ventilation, so that, in this case, the blower serves a double purpose of ventilating a hot room and at the same time providing air for the furnace.

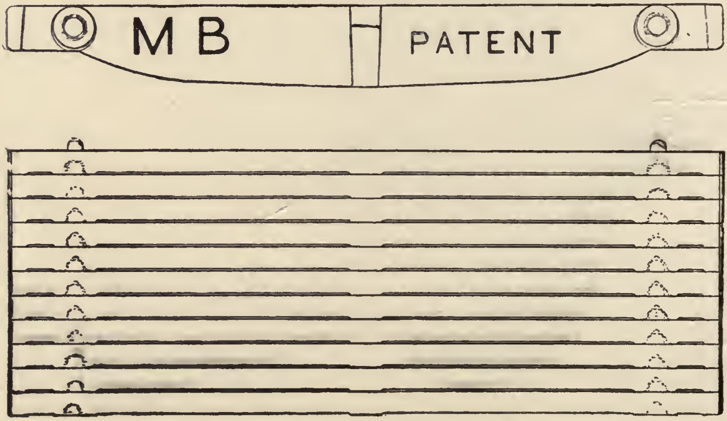


Fig. 9.—Meldrum's Grate Bars.

This furnace may be used for other purposes besides steam boilers, such as refuse destructors, brewing coppers, evaporating pans, etc. In Fig. 10 is shown a Meldrum furnace applied to a brewing copper. The chief advantages of this furnace are that it will burn a larger quantity of fuel on a grate of given size than an ordinary furnace, the temperature of combustion is higher, and, the draught being more under control than where the draught has to depend on the chimney, the

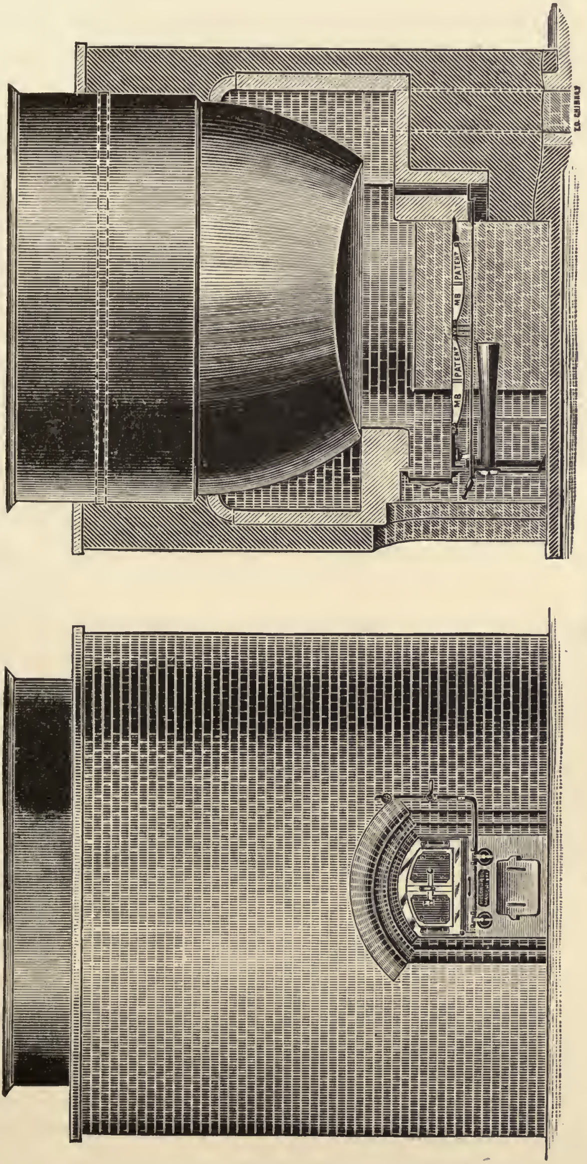


FIG. 10.—Application of Meldrum Furnace to Brewer's Copper.

supplementary air supplies can be so regulated as to effect good combustion without smoke. They are particularly suitable for boilers where the natural draught is deficient, or when more steam is wanted than can be produced from the boilers in the ordinary way.

GRANGER'S FORCED DRAUGHT SYSTEM.

In this system air is forced under the grate bars, the space beneath these being closed, and the air maintained at a pressure. In a Lancashire boiler, two blowers are used for each flue. The action of these blowers is simply to induce a draught of air through a trumpet-shaped inlet pipe, by the action of a central jet of steam, which carries the air along with it. In most of the steam-jet systems only one actual jet is used in each blower, but in Granger's system the jet is a compound one, consisting of a central jet and three supplementary jets placed concentrically with regard to the first. These three supplementary jets are made so as to be adjustable by hand, and by this arrangement a considerable margin is provided for the quantity of steam used. The adjustment is simple, and is made by turning a milled head, which is placed externally to the boiler front. The fire bars are of special design, being provided with very narrow spaces between them, so as to make it possible to burn small coal. The advantages of this, like all other forced draught systems, is that it provides an increased draught and makes it possible to burn very small and cheap fuel, gives a greater duty to the boiler, and makes it possible to get a larger yield of steam from a boiler than could be obtained by means of natural draught. Where the chimney draught is bad, a forced-draught system is especially applicable.

When using ordinary coal Granger's system of forced draught cannot be said to provide a smokeless fire, but very little smoke is produced when using anthracite or a mixture of anthracite and coke breeze.

Where perfect smokelessness is desired, Mr. Granger supplies an arrangement by which streams of heated air are allowed to mix with the volatile products just beyond the bridge. This is said to prevent the emission of smoke by supplying the requisite quantity of air for the combustion of the hydrocarbons, and at the same time maintaining a high temperature in that part of the fire beyond the bridge.

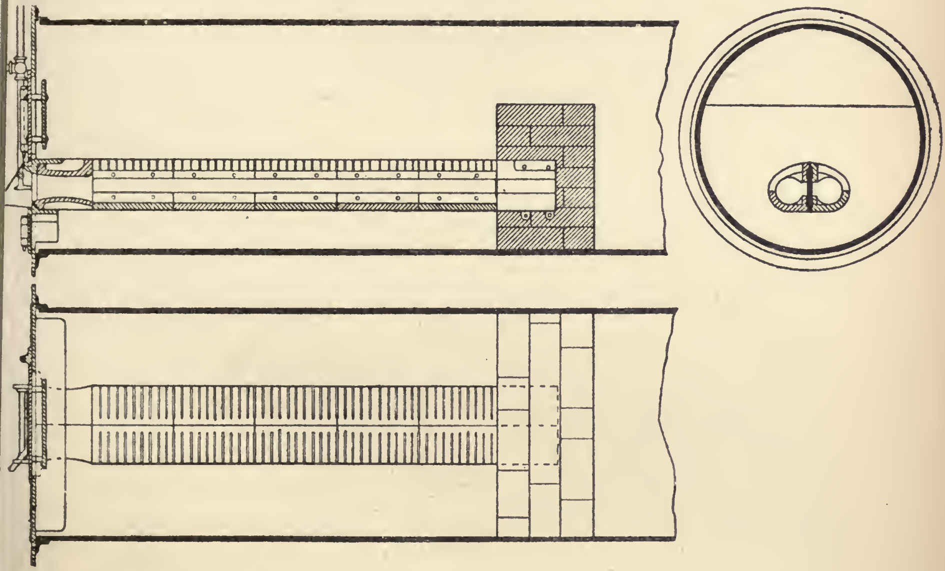


Fig. 11.—Mason's Grate.

Mason's Forced Draught Furnace.

The peculiarity of this system lies in the form of the grate bars. These are shown in plan, longitudinal and transverse section on Fig. 11. The grate consists of two hollow tubes supported in the centre of the fire. The upper surface of the tubes is formed of gratings, the bars being placed transversely.

In each of these two tubes is placed a steam jet blower which carries a current of air into the tubes, from which it goes to the fuel through the interstices between the bars. The grate, thus formed of the curved upper surfaces of the two pipes, only occupies about one-third of the width of the flue. The flue tube is kept filled with ash up to the level of the air pipes, and as more accumulates, the ashes are raked out from below by the fireman. When the fire is to be started, ashes are thrown into the boiler flue up to the level of the grate, and then a fire is made in the usual way, and built on the top of the ashes. It is claimed for these furnaces that a cheap fuel can be used, better evaporative efficiency can be attained even by the use of ordinary coal, and that, there being no necessity for opening the ashpit doors for the removal of ash, there is no possibility of air getting into the flues and lowering the efficiency. This latter end is attained by keeping the ashpit and air space below the grate entirely separate.

INCANDESCENT ARCHES AND BRIDGES.

Of these may be mentioned Welton's diagonal grid and "Greaves' Arches".

Welton's Diagonal Grid.—This is a device for obviating the emission of smoke quite independently of the air supply. An iron grid is fixed in the flue a little way behind the bridge, sloping at an angle of about 45°, with the lower end nearer the bridge. Lumps of asbestos, somewhat similar to those used on a gas fire, are placed on the sloping grid. These become incandescent from the heat of the fire, and any smoky gases impinging on this incandescent surface are supposed to be raised to a higher temperature and be more completely mixed with the air and consequently consumed. See Fig. 12.

Greaves' Incandescent Arch.—The object of this is precisely the same as that just mentioned. The action of this arch is described in these words: "Under the action of the heat of the furnace the block or slab becomes incandescent, and as the smoke and unconsumed gases strike or pass through they become burnt or changed into carbonic oxide, and thus tend to increase the economy of the fuel and abate the smoke". The presumption apparently is that in the gases there is free carbon and free oxygen, and this carbon takes up the oxygen to form carbonic oxide, and this again burns with what oxygen there is left, or it passes away as CO. These two arrangements have never been generally adopted. Although they are said to very materially diminish the smoke, they have one or two fatal defects:—

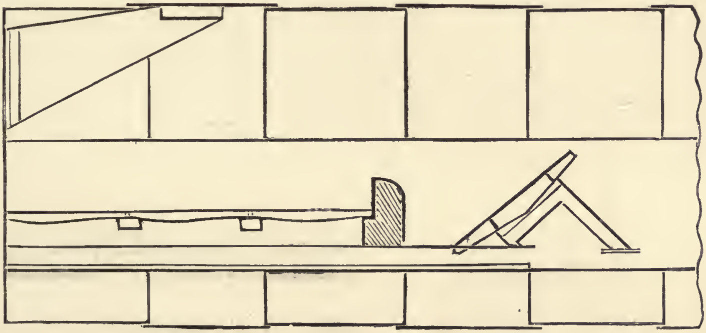


FIG. 12.—Welton's Incandescent Grid.

1. They are designed on the assumption that black smoke leaves the grate, which ought not to be the case.
2. They obstruct the passage of the gases and thus interfere with the draught. It is significant that in the case of some of these, steam jets had to be used to assist the draught.
3. These grids and arches are very perishable when exposed to the rush of the flue gases, and it has been

found that a considerable cost was involved in repairs and renewals.

INDUCED CURRENTS OF AIR BY MEANS OF STEAM JETS.

This plan for reducing the production of smoke has been very largely used in furnaces of all kinds.

The accompanying Fig. 13 shows the arrangement of an apparatus of this kind as applied to a Lancashire boiler. The appliance is perfectly simple both in its application and its use. Two half-inch copper pipes are taken from the upper part of the steam space, down the front of the boiler, and introduced into the furnaces just above the fire door. The pipes thus entering the furnace are taken in for about six or eight inches, when they terminate in nozzles, forming steam jets which are about one-eighth of an inch in diameter. The nozzle can easily be made by simply reducing the copper pipe and working it into the desired shape. Taps are fixed between the boiler and the nozzles. The direction of these should be towards the fire bridge as shown in the sketch. When fuel has been put upon the fire the jet is turned on, and at the same time the fire door is left slightly open, or if there is an air valve in the door this can be opened and the fire door closed. The action of the jet is to induce a

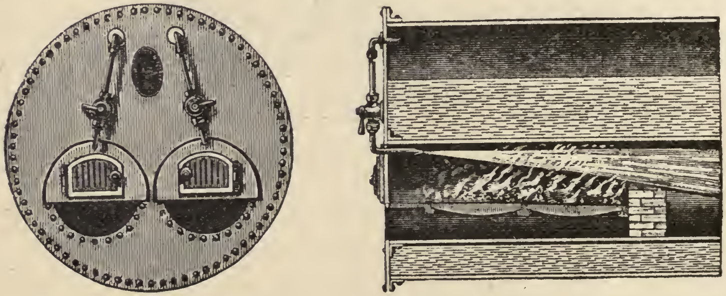


FIG. 13.—Whittle's Steam Jets.

strong current of air, which mixes with the hydrocarbons as they come off from the fuel, and causes complete combustion of these. The action of the air current so induced is also to make the flames to leap upwards to the furnace crown, and in this way bring about a more perfect commingling of the gases and air.

When the possibility of smoke has disappeared the jets are to be turned off and the air door closed.

For application to an existing furnace which is liable to produce smoke this appliance is simple and cheap and can be easily fixed. Its great drawback is that it is not automatic, but is entirely dependent for its proper use on the stoker.

The particular form which has been described is one that is no longer on the market, by name the "Whittle Steam Injector".

In its later forms the air was induced through a two-inch pipe, down the centre of which the steam jet played. This arrangement obviates any opening or shutting of the fire door.

The same device is used by many other makers in slightly different forms.

AUTOMATIC REGULATION OF AIR SUPPLY.

Many attempts have been made to effect a satisfactory regulation of the air supplied to the furnace by automatic means, but very few of the appliances designed for this purpose have been in any way successful. The conditions to be fulfilled in arranging a satisfactory air supply to the furnace of an ordinary hand-fired boiler are not difficult to appreciate after what has already been said upon the subject of air supply. In the first place, a constant quantity of air flows into the ashpit, this being the amount which is necessary for the combustion of the carbon in the fuel. In addition to this constant supply beneath the bars, air must be supplied above the bars and possibly at the bridge, for the purpose of burning the hydrocarbons which are driven off, and also to help in completing the combustion of the carbon. This air supply above the fire must be intermittent, the maximum being allowed to reach the fire just before or after firing, and continuing for a time, this depending upon the kind of fuel which is being used and the chimney draught.

These are the conditions which have to be satisfied, and the appliance used must be so designed as to fulfil them as nearly as possible. In most cases the supplementary air is admitted either above or through the fire door or at the bridge, or both at one time, and the automatic appliance must be designed so as to open the doors through which this supply is admitted when stoking begins, allow the doors to remain open for some minutes, and then to close very gradually as the combustion of the hydrocarbons becomes complete, when the quantity of supplementary air which is required will become less and less. Also, as the object of an automatic regulation of the air supply is to render this supply, which is necessary for the proper and smokeless combustion of the fuel, independent of the firemen or stokers, it is necessary that it be brought into action by one of the movements necessary to stoking, such as opening the furnace door.

Appliances Designed by the Author.

In order to illustrate the meaning of these necessary conditions, the following descriptions of two automatic appliances designed by the writer may be useful:—

One of these appliances is shown in front view in Fig. 14. The view represents the front of a Cornish boiler, with the usual furnace and fire door. Above this door is an air valve or door turning on a central pivot, and actuated by the pressure of the steam from the boiler on the piston of a small cylinder, shown to the left of the air door. When the pressure on this is released a spring, which has been previously compressed by the pressure of the steam, again closes the door. The chief part of the regulation is effected by the pressure of water and steam on the two pistons of the tandem cylinders, shown. The smaller of these contains a piston which is acted upon by the pressure of water from the water space of the boiler as shown. The small valve shown is so made that the water can flow freely from the boiler to the cylinder, but it can only proceed back again through a very small opening, which can be altered, and constitutes the regulating device. In the other cylinder there is also a piston, which is rigidly connected to the first. This second piston is acted upon by the steam from the steam space. The action of the apparatus may be described as follows: The fireman opens the door to throw on a new supply of coal. This opening of the door turns a small spindle which is attached to the door, and this again carries a crank which

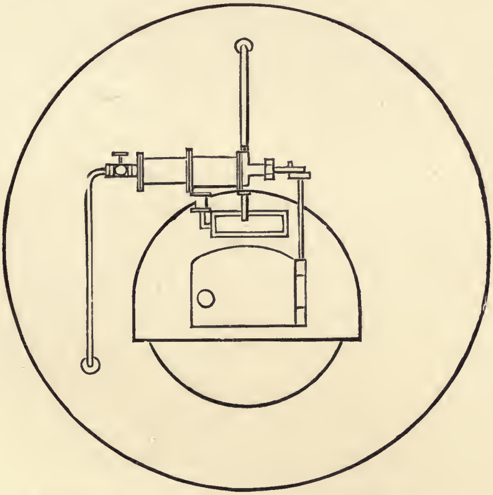


Fig. 14.—The Author's Automatic Device.

pulls on a rod. The pulling of this rod opens an interior valve and allows steam to proceed from the boiler and to press upon the larger piston. This cylinder is of larger diameter than the other, and, consequently, the pressure of the steam and water per square inch being the same, the pistons move from right to left, and the water is very slowly driven out. The valve is so regulated that it takes three or four minutes to complete the stroke. This covers the time of stoking, and sufficiently long afterwards to prevent the emission of smoke. On the completion of the stroke an interior rod is pulled and the steam valve again closed. This closing of the steam valve releases the pressure from the piston and the water pressure, no longer being held in check, carries the smaller piston back to its original position, and the cycle is complete, ready for the next firing. When the steam is first turned on, besides going to the cylinder it is also allowed to flow into a top jet, through a pipe which is shown entering at the top of the fire door, and also into the air door cylinder. So that, by the simple process of opening the fire door, not only is an air door opened for the admission of a supplementary air supply, but a steam jet is turned on for the purpose of assisting in the influx of this air. When the steam valve is closed at the end of the stroke of the pistons, the air valve automatically closes and the steam jet ceases blowing.

This apparatus has been used and has been found to go through its cycle of operations with great exactness, but the method of regulation was found to be extremely delicate, for so small had the opening to be through which the water was allowed to escape, that a very small quantity of dirt or other impediment getting into this opening was sufficient to put the whole apparatus out of gear. This delicacy is a great drawback in any appliance which has to be subjected to the rough usage common in a boiler house. Another difficulty which is found, where the regulation is effected in this by slow-moving pistons, is that there may easily be a leakage past the water piston, which allows more water to escape than that which is necessary for regulation, and the whole end of the appliance is defeated.

In a later design, which is intended to effect rather different results, these being the opening of an air door in the bridge, and possibly one at the front of the furnace also, the principle of the two tandem cylinders is adhered to, but these are made larger, so as to provide a greater volume to be dealt with and so make the apparatus less delicate; and an improvement has been effected as regards the packing of the water piston. In addition to this, the cycle of operations is changed, so that the action may be much more certain than before.

Saxton's Apparatus.

In 1892 a patent was taken out by E. & J. Saxton of Sheffield, for an appliance which was intended to effect an automatic regulation of the supplementary air supply admitted through the fire bridge. The operation of opening the fire door also caused an opening of the air door in the bridge, and, at the same time, forced the piston of the regulating cylinder to the bottom of its stroke. These three operations were performed by the force exerted by the fireman in opening his door by means of suitable connecting rods and levers. The cylinder was filled with oil or glycerine or other suitable liquid, and the piston could pass freely from end to end of the cylinder in one direction by reason of a valve in the piston itself, but this valve only opened in one direction, and the movement of the piston to the opposite end could only occur when the liquid was allowed to pass from one side to the other by way of a special passage, which was closed by a regulating valve.

When the fire door was shut, the piston was released and slowly travelled back to its opposite end, at the same time closing the air valve in the bridge. This closing movement was brought about by the falling of a heavy balance weight, which of course had to be raised in the first instance by the opening of the door. The author has no definite information as to the behaviour of this apparatus, but in his opinion it suffers from one fatal defect which would preclude its general adoption : the objection is that all the work of opening and closing the fire door has to be performed by manual labour. One can conceive that a very great deal of force would have to be applied to the fire door in order to complete all the operations mentioned, and, even then, there would not be much margin left for the definite and certain closing of the air door at the right time. The author's experience with appliances of this kind has led him to believe that steam, hydraulic or other power must be used for doing the bulk of the work, and the manual work ought only to be used for the purpose of putting the other into operation.

OATES' APPARATUS.

In this apparatus, again, a cataract cylinder is made use of for the purpose of regulating the speed of closing. From the patent specifications in which this apparatus is described it appears that the supplementary air is admitted at the fire door through a special air grid and also at the bridge. The opening of all the air valves is effected by steam power utilised in a small cylinder provided for the purpose, but this apparatus is only semi-automatic, in that the steam must be turned on at the right time by manual force. This is, however, a great improvement on the apparatus last described.

AUTOMATIC SUPPLY OF AIR THROUGH THE DOOR.

One of the earliest forms of an appliance of this kind was that of Prideaux, of which an external view is shown in

Fig. 15. The fact of opening the door for firing caused the simultaneous opening of a series of air passages through the door. Through these the supplementary air was allowed to flow on to the fire for a time after stoking, at the end of which the air doors or louvres were automatically closed by their own weight, the time of closing being regulated by the flow of some fluid in a cataract cylinder. This apparatus was found to be very delicate, and required frequent repairs. Many similar devices have been brought out from time to time.

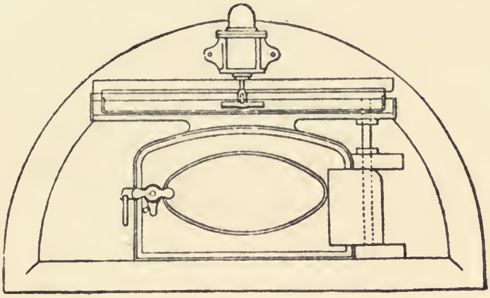


Fig. 15.—Prideaux Fire Door.

Down-draught Furnaces.

Though not attempted in this country as yet, the down-draught system of firing has achieved a considerable amount of success in America. Of these furnaces one of the most successful, the Hawley Down-draught Furnace, is described by Mr. Bryan Donkin as being very smokeless and economical in its working. In this furnace there are two grates or sets of fire bars, one placed above, the other in the flue. The upper one, in which the greater part of the combustion takes place, is composed of water tubes connected with the water space of the boiler, these being so arranged that a thorough circulation takes place, by which means the bars are kept cool and some heat is transmitted to the water from the fire bars. There are one or two rows of tubes. The green fuel is fed by hand on to these upper bars, and the earlier part of the combustion takes place there. In some cases the bars of the upper grate slope downwards towards the back of the boiler to help the circulation. The back of the upper grate is closed, so that the draught can only pass downwards through the burning fuel. This is the gist of the whole arrangement. The gases from the burning coal pass downwards, through the most incandescent part of the fuel, and play upon the fire which is burning on the lower grate. This consists of incandescent carbon which has fallen through the upper bars, and is completely incandescent. A secondary supply of air is admitted between the two grates, so as to aid in the combustion of the hydrocarbon gases which are carried down from above.

In two results of trials quoted by Mr. Donkin, in one of which the Hawley grate was applied to a tubular boiler and in the other to a Babcock boiler, the economy results were extremely good, the boiler efficiency and the evaporation being very high in both cases, and, what is very important, the combustion was smokeless.

The combustion is not equally divided between the two grates, some 90 per cent. taking place on the upper bars and only the last stage of incandescence occurring on the lower oven.

Horizontal-draught Grates.

These are very similar to the American down-draught grates, but are not in all respects so satisfactory. The Doneley grate is much used on the Continent. It is suitable for externally fired boilers, and must be placed externally to the boiler. The fuel falls in a vertical column on horizontal grate bars, but the front of the furnace is closed by a set of vertical bars, and, as the layer of clinker and ash prevents any air coming up through the fuel from below, the air for combustion flows through the vertical bars in a horizontal stream.

The greener coal being at the front, and the more incandescent further back, the hydrocarbons, as they are distilled off, must pass through the incandescent carbon behind, and so become consumed. The back of the grate is closed by a set of water-tube bars, which prevent the passage of any fuel beyond this point and at the same time serve to take up a large amount of heat from the gases.

This grate behaved better than any other, as regards smoke prevention, in the Paris trials of 1897, and at the same time showed good evaporation and boiler efficiency.

Stepped Furnaces.

A good example of these is the "Tenbrink," which is largely used on the Continent. Its chief features are the arrangement of its bars in steps, forming a slope of about 45 degrees. Air is admitted both above and below the fuel, and the combined action of the two sets of air currents results in a thorough mixture of the air and the unburnt gases. The grate is said to produce good results, but it is costly in the first instance and the labour involved in firing is rather high.

The Wilton Furnace.

In this grate there are no fire bars, but there are two cast-iron pipes lying at the bottom of the flue tube. At the front ends of the pipes are steam jets, which inject currents of air, which pass into the fuel and maintain combustion. A secondary air supply is admitted above the fuel. The fuel, which may be cheap slack, forms a mass about ten inches thick resting on the bottom of the flue tube.

CHAPTER III.

STOKING BY MECHANICAL MEANS.

It is clear that there are many disadvantages in feeding boilers by hand, both as regards economy and smokelessness. The stoking must of necessity be intermittent, and, consequently, the air supply must be also intermittent and variable. If this air supply is carelessly regulated, smoke will be given off, in small or large quantities; or, if the fire doors are left open too long or any other air supply is wrongly timed, a large amount of waste may be caused in heat carried away up the chimney. If, then, the fuel can be supplied in a continuous stream, as it were, the air must be delivered along with this fuel in a like manner, and can be regulated so as to be neither too much nor too little. This is one of the objects of feeding by means of what are known as mechanical stokers. In these the fuel is fed into the furnace by mechanical means, either at very short regular intervals of time or in a continuous slow-moving stream. These mechanical stokers may be broadly divided into two classes, namely, "sprinkling" and "coking" stokers. Of the former class, the best known machines are those of Bennis and Proctor; of coking stokers there are a good many on the market, such as the Vicars, Cass, Sinclair, Proctor and Meldrum. It will be well to examine one or two representative types.

BENNIS' STOKER.

In this stoker the coal, which must be fairly small and dry, is supplied to a hopper either by hand or by means of an automatic conveyer. This hopper is placed in front of the boiler and above the furnace. The coal is first allowed to fall on to a plate in front of a mechanical pusher, which has a reciprocating movement, and each time this moves forward it pushes a small quantity of the coal further along the plate, where it falls over the edge of the shelf. As it falls it is caught on the mechanical shovel, which is simply for the purpose of throwing it upon the fire. This shovel is worked by being drawn back against the pressure of a spring, and, when it has been drawn fully back, it is released, and the coal is thrown outwards over the fire. The distance to which the fuel is thrown by the shovel varies automatically with each throw: one throw sends it close under the bridge, the next a little nearer the door, the third nearer the door again, and the last throw delivers it just below the stoker near the door. By this means the coal is distributed uniformly over the whole surface of the fire, which is never at any point very far from incandescence. It is held that this conduces to smokelessness. In addition to the sprinkler device for throwing the coal on the fire, the makers of this stoker have an arrangement by which the fire bars are given a slight motion in such a way that the clinker and ash is being constantly loosened, and at the same time slowly carried towards the bridge, where it is deposited in the ashpit. Provision is made for hand-firing if it becomes necessary, owing to the work being intermittent or to a breakdown of the mechanism. The whole of the work is done by power derived from the shafting of the factory or from a small engine specially provided for the purpose.

Proctor's Sprinkling Stoker.

The earlier stokers made by Messrs. Proctor were all of the sprinkling type, but they have now a very excellent combined sprinkling and coking stoker on the market, which will presently be described. In the sprinkler there is only one hopper for a two-flued Lancashire boiler, and the coal, after falling from the bottom of the hopper, is pushed by a ram alternately to the left and to the right, first into one furnace and then into the other. On leaving the ram the coal is thrown by means of a mechanical shovel upon the fire. These shovels are actuated by springs, and have three throws of varying distance.

Vicars' Mechanical Stoker.

This, one of the earliest of the successful mechanical stokers, is at the present time very largely used. It may be regarded as a typical *coking stoker*, and the principles here adopted are made use of in nearly all the other coking stokers, with differences in detail, and, in some of the later machines, additional appliances for increasing the duty of the furnace.

In Fig. 16 is shown a section of the Vicars stoker, which will serve very well to make clear the manner in which this machine works.

The fuel is fed from the hopper or magazine into boxes, usually two to each flue, from which it is gradually pushed by reciprocating plungers alternately on to the dead plate. Air spaces are provided immediately under these boxes and also through the dead plate to facilitate the rapid coking of the fuel. From the dead plate it is pushed on to the moving fire bars, which gradually take the burning mass further into the boiler. The unconsumed coke with the clinker and ash is delivered over the end of the fire bars into the flue, where it forms and maintains a bank, which acts as a bridge and prevents any free air passing direct into the boiler. Combustion is completed at this point, and the clinkers are removed at intervals according to circumstances.

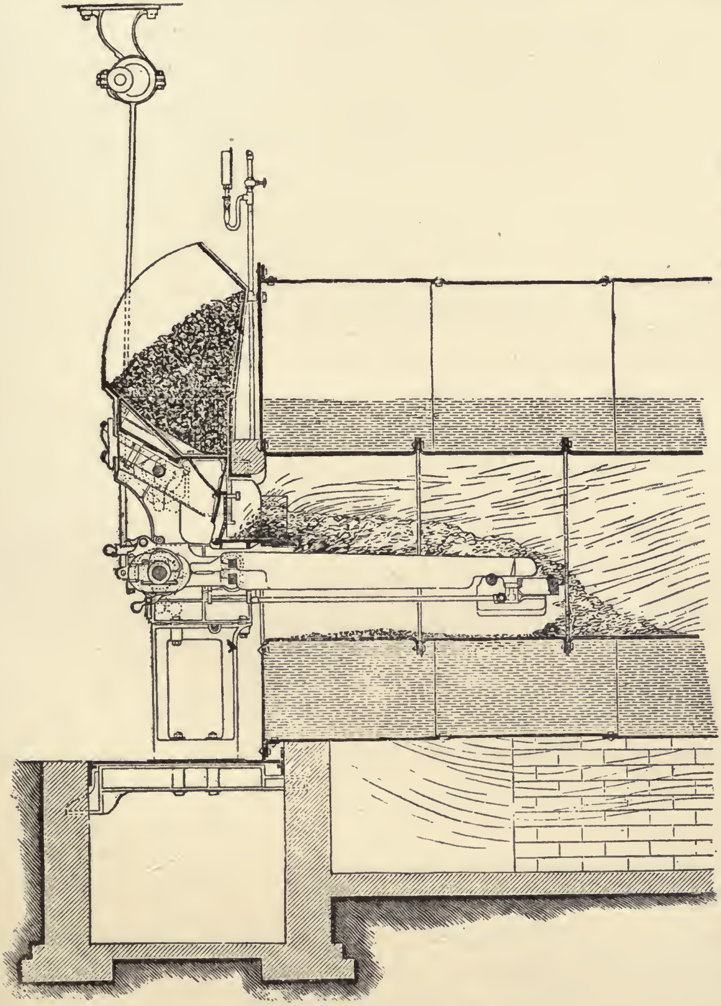


FIG. 16.—Vicars' Mechanical Stoker.

A bridge of firebrick is built in the furnace flue some feet from the end of the bars, so as to form a kind of combustion chamber.

The supply of fuel and the travel of the bars are easily regulated independently of each other, and a separate gear is supplied for working each flue. The coal feed is varied by altering the rate of motion of the plungers, which, by a simple movement of a short lever, can be instantly adjusted over a wide range, or stopped altogether. The motion of the bars is worked in the same manner, and the actual stroke can be varied up to about four inches. The bars of each furnace are arranged in two sets, each composed of the alternate bars and moving together, travelling in towards the bridge, but returning at separate intervals. Thus the fuel is carried inwards by the simultaneous action of both sets of bars, and remains in place without being disturbed by the return of either set. Each successive inward movement of the bars serves to carry the fuel, together with the clinker and ash, nearer to the end of the grate, where the mass at length drops over the end of the bars as already described.

The various parts receive their movement from either an overhead or underground shaft, running at a speed of twenty revolutions per minute. Doors are provided which can be used for hand-firing if necessary.

The Vicars furnaces are capable of burning the most bituminous fuels at rates varying from fifteen to fifty pounds of coal per square foot of grate *smokelessly*, and at the same time maintaining high percentages of CO_2.

It is stated that, although a portion of the unconsumed fuel is delivered over the end of the bars, it has been shown by tests that the proportion of fixed carbon in the ash is very small, and that the ash exceeds by only a very small amount that found in laboratory tests.

The stoker for water-tube boilers is somewhat different in its arrangement. A firebrick arch is built over the moving bars for a distance of about three feet from the front of the boiler, so as to raise the volatile hydrocarbons to a sufficiently high temperature when brought in contact with the heated air as to become inflammable. The fuel on arriving at the end of the bars drops on to another set of inclined bars, which can be tipped if desired, and the combustion is completed as in internally fired boilers.

The following comparative trials on Babcock and Wilcox boilers, between hand-firing and machine-firing with Vicars stokers, are instructive. The boilers were those of the City of London Electric Lighting Station. The tests were made in 1894. Only the most important figures are given here :—

COMPARATIVE TRIALS BETWEEN HAND-FIRING AND MACHINE-FIRING.

	Hand-firing.	Vicars' system.
Description of fuel used	Nixon's Navigation	Bituminous rough, small.
Price of fuel used	16s. per ton.	10s. per ton.
Average steam pressure	145·9 lb.	157·5 lb. per sq. in.
Water evaporated per hour	13,170 lb.	13,683 lb.
Water evaporated per lb. of fuel at and from 212°	10·50 lb.	10·78 lb.
Water evaporated per lb. of combustible at and from 212°	10·93 lb.	12·12 lb.
Cost of evaporating 500 gallons	40·8d.	24·8d.

There is sufficient heat present to drive off the volatile gases before the fuel has had time to travel far along the bars. These volatile hydrocarbons as they come off from the coal are carried by the chimney draught across the hottest part of the furnace, where the fuel is incandescent and at a very high temperature. Sufficient air being supplied for the combustion of these hydrocarbons, the temperature is so high that their combustion takes place at once, and the gases given off are colourless, and are simply the products of perfect combustion, plus a certain amount of excess air. The whole operation is gradual and continuous, and there is no admission of a gust of cold air when it is not wanted. In a hand-fired furnace the air supply must be intermittent to suit the intermittent fuel supply, but in a coking stoker the conditions are such that the air supply may, and, indeed, must be uniform and continuous.

CASS' COKING STOKER.

A front view and a longitudinal section of this stoker are shown in Figs. 17 and 18.

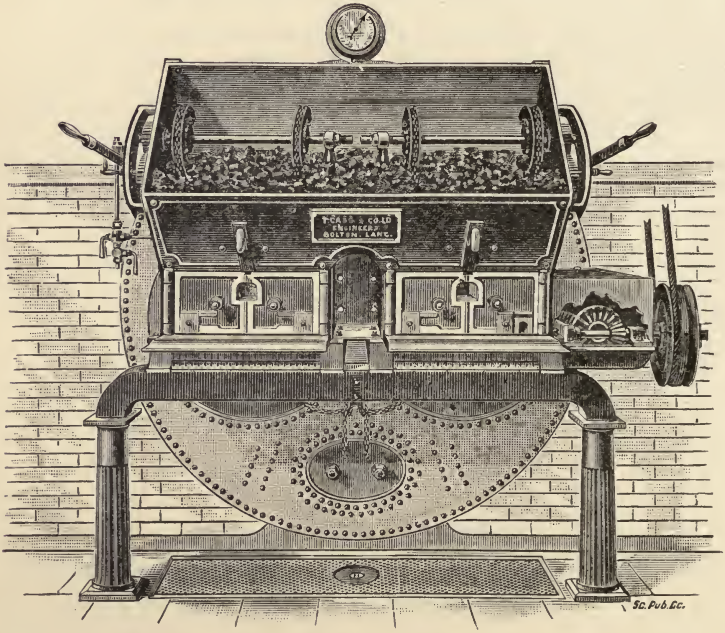


FIG. 17.—Front view of Cass' Mechanical Stoker.

Here the coal is fed into a hopper, which, in the case of a Lancashire boiler, is carried right across the front, thus supplying both furnaces from one hopper. The hopper will hold about half a ton of coal. From the hopper the coal is allowed to fall on to the bars through a sliding door, which can be adjusted to suit various grades of fuel. In this stoker the bars extend some distance beyond the front of the furnace, and the coal is allowed to fall direct on to them, without the use of any distributing mechanism or pushers. A longitudinal motion is given to the bars, by which the coal is worked gradually along from the front to the back of the grate during the time when combustion is taking place, the speed of travel being so arranged that the fuel reaches the back end of the bars just as the combustion is complete, and the unconsumed ash and clinker fall over into the ashpit to be raked out by the attendant. The coking begins soon after the fresh coal has fallen on to the bars, and the layer of fuel diminishes in thickness but increases in intensity of temperature as the

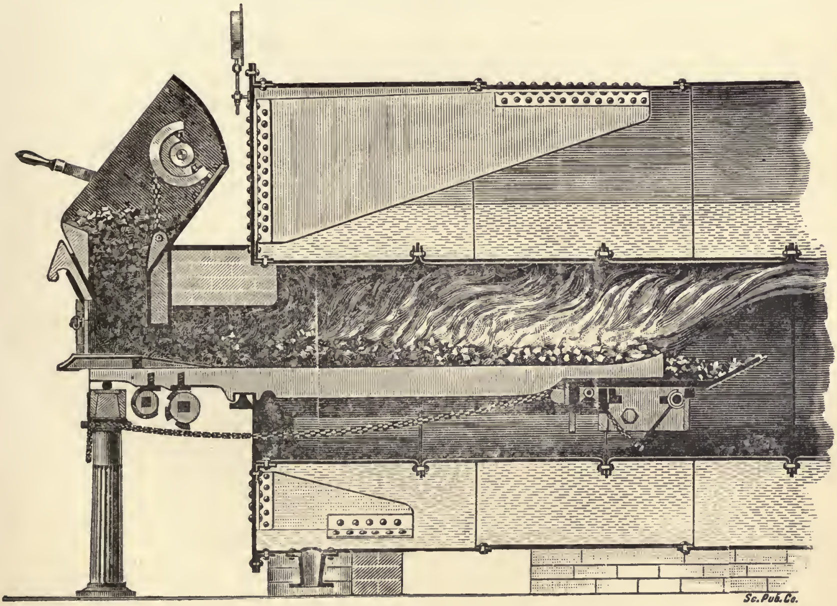


FIG. 18.—Section of Cass' Mechanical Stoker.

coking becomes complete and the back end of the bars is approached.

As is usual with all stokers of this class the passage of the volatile gases given off from the green coal at the front end over the glowing white-hot fire secures their complete and smokeless combustion. Below the bridge is a door which can be opened for the purpose of raking out the ash and clinker.

The working parts are few, and designed with a view to the reduction of wear and tear to a minimum, the rubbing parts of the bars and the tappets which work them being faced with steel. The mechanism of this furnace is driven from the shafting of the factory by means of a three-quarter inch rope.

The combustion of coal in this furnace is smokeless, and, in this connection, it may be remarked that in the report of the Committee for Testing Smoke Preventing Appliances, it is stated that the Cass stoker showed very excellent results indeed.

SINCLAIR'S MECHANICAL STOKER. (See Fig. 19.)

This is a stoker of the coking kind, and has been largely used, especially in Scotland. Like others of this same type, the fire burns on flat horizontal bars as in an ordinary hand-fed furnace, but there are several differences in the construction which the makers claim as improvements over the usual arrangements. The pusher or plunger used for sending the coal forward into the furnace is made the entire width of the fire, which arrangement tends to keep the fire perfectly even and level. The motion is given to the bars by means of cranks on a shaft placed in front of the furnace and revolving once or twice per minute. This shaft is made exceptionally strong, being $2\frac{1}{8}$ in. diameter. The furnace bars possess two movements, one forward and the other backward, in alternation, as well as an irregular motion whereby the clinker is prevented from adhering to the bars. The movable bars

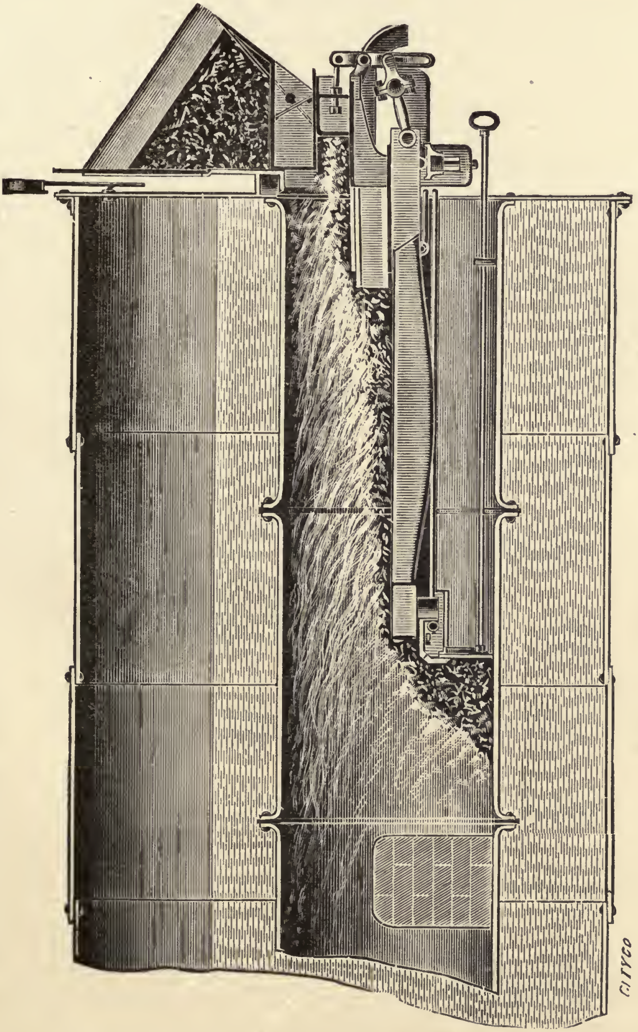


FIG. 19.—Section of Sinclair's Mechanical Stoker.

gradually carry the fire backwards, and the ashes and clinker remaining at the end of combustion fall over at the ends of the bars into the pit, from whence they can be raked out through a door provided for the purpose. This door is kept closed the greater part of the time during which the furnace is in action, and in this way any cold air is excluded. The plunger or pusher used is worked by means of an adjustable screw and lever, so the amount of feed can be regulated, and in this way the steam maintained at a uniform pressure. The writer has seen several of these stokers at work, and, like most coking stokers, the *combustion is smokeless* and efficient. These facts are emphasised in the following extract taken from the official report of the Smoke Abatement Committee: "It may be observed in the few results of tests given in Table xxv. that the only mechanical stoker which worked with complete smokelessness was the coking stoker of G. Sinclair, tested at the exhibition on a Cornish boiler. Of the systems of mechanical stokers which have been tested that of G. Sinclair was the steadiest in action, and was the only one which worked without the interference of the occasional aid of the shovel or the rake. The excellence of the stoker was also proved by the complete absence of smoke, already noticed, and by the efficient manner in which it transported and rejected the heavy masses of clinker that were formed." This extract refers to the Smoke Abatement Exhibition, held at South Kensington, London, in 1882.

Proctor's Coking Stoker.

An improvement on the sprinkling stoker which has been described has been effected by the introduction of Messrs. Proctor's later form of stoker. This differs from other coking stokers in that the sprinkling arrangement is still adhered to, to some extent, and with this is combined an arrangement of the bars which has the effect of converting the stoker into one of the coking kind. The shovel or thrower is used as before, and deposits the fresh fuel on the top of the body of the incandescent fire. Combined with this, a movement is given to the bars by which the coal is gradually carried forward to the back of the furnace. The bars themselves are made with a slight inclination towards the back, which, with the to and fro movement of the bars, derived from the mechanical arrangement provided, causes this travelling of the fuel towards the

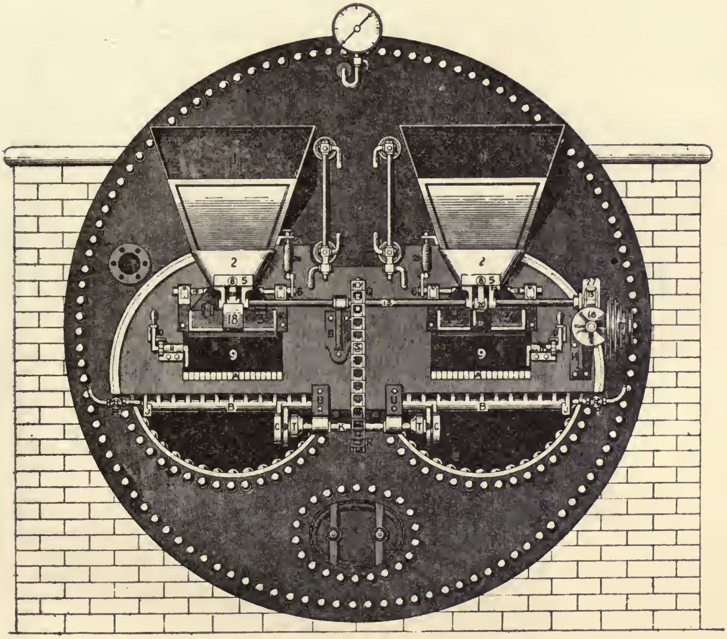


FIG. 20.—Front view of Proctor's Stoker.

STOKER.

1. Cast-iron hopper. 2. Ram box. 3. Shovel box. 4. Radial shovel. 5. Ram. 6. Spring lever. 7. Tappet fingers. 8. Screw for regulating ram. 9. Hand-firing door. 10. Hand-firing handle and catch. 11. Hand-firing bracket. 12. Shovel shaft. 13. Driving shaft. 14. Driving end bracket. 15. Worm and wheel. 16. Bevel wheels. 17. Cone pulley. 18. Tappet wheel lubricating tap. 19. Centre bracket. 20. Finger for working ram. 21. Tappet wheel. 22. Shovel fingers. 23. Ram shaft bracket. 24. Flap. 25. Spring brackets. 26. Ram lever shaft. 27. Lubricating cover for driving brackets. 28. Shovel spring.

back. Instead of the bars being drawn forward piecemeal and all sent back together, which involves somewhat complicated mechanism to effect, it is found that by having them on the slope, and by moving every alternate bar, there is a much greater chance of preventing the bars from becoming soldered together and keeping the air spaces free, and, at the same time,

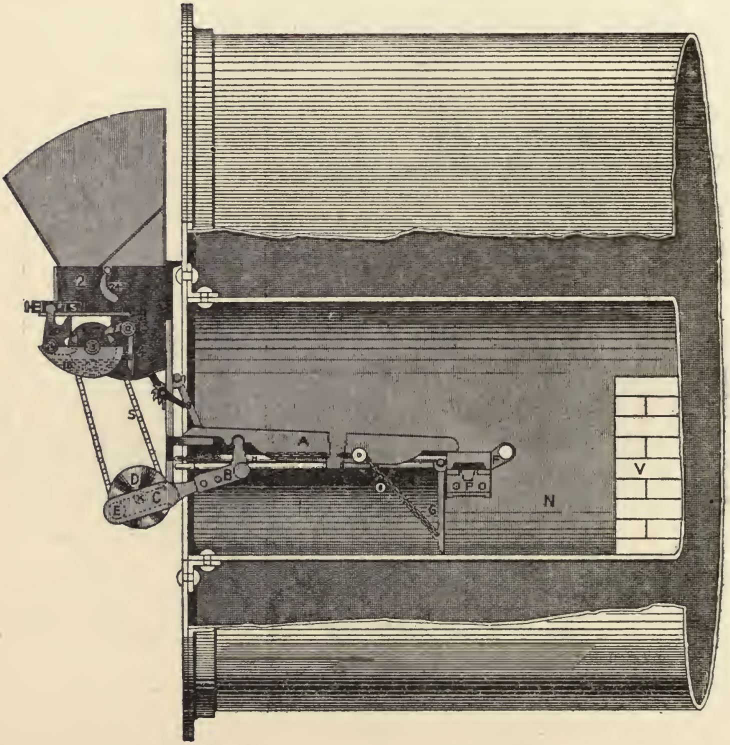


Fig. 21.—Section of Proctor's Stoker.

BARS.

A. Grate bars. B. Rocking shaft. C. Slotted lever. D. Face plate. E. Bowl and Steed. F. Steam bridge. G. Ashpit door. H. Jet pipe. J. Rocking shaft brackets. K. Bar motion shaft. L. Steam pipe to steam bearer. M. Steam valve. N. Ashpit. O. Ashpit door chain. P. Steam bridge bracket. Q. Top chain wheel. R. Bottom chain wheel. S. Chain for drawing bars. T. Clutch box. U. Bar shaft brackets. V. Brick bridge.

the fuel is carried along as may be desired. The bars rest on a bearer, which is provided with an arrangement of steam jets for keeping the bar ends cool, so as to allow of an active fire being kept up the whole length of the bars without fear of burning the backs down. Without this steam bearer the fire has to partially burn itself away before getting to the back, and so reducing the duty of the back ends of the bars. Very little steam is used in the bearer, being just sufficient to keep the bars cool without blowing up the fire. The traverse of the bars can be adjusted, and also the speed of movement.

The effectiveness of this arrangement of Messrs. Proctor is proved by the large number at work, some eight thousand having been supplied; and, as regards smoke, ample proof of smokelessness is given in the results of the Paris Smoke Trials, which will be referred to later. In this connection it is sufficient to say that Messrs. Proctor shared with a continental maker the highest prize given for combined efficiency and smokelessness.

Two views of this stoker are shown in Figs. 20 and 21.

THE MELDRUM "KOKER" STOKER.

This stoker, of which a front view is shown in Fig. 22, is the latest form of coking stoker, and contains some features which may be expected to give it a distinct advantage over others of this class. The forced-draught grate made by Messrs. Meldrum has already been described and illustrated, and it is the application of this forced draught to a coking stoker of new design which constitutes the improvement. In all coking stokers, where a forced draught is not in use, the weak point is the comparatively low duty, that is to say, the amount of water evaporated in a boiler of given size is low as compared with the evaporation given in hand-fired boilers, especially where forced draught is in use, although the combustion may be, and generally is, perfectly smokeless. With the object, therefore, of maintaining a high boiler duty, combined with a smokeless chimney, Messrs. Meldrum have designed a coking stoker, and to it they have applied their system of forced draught.

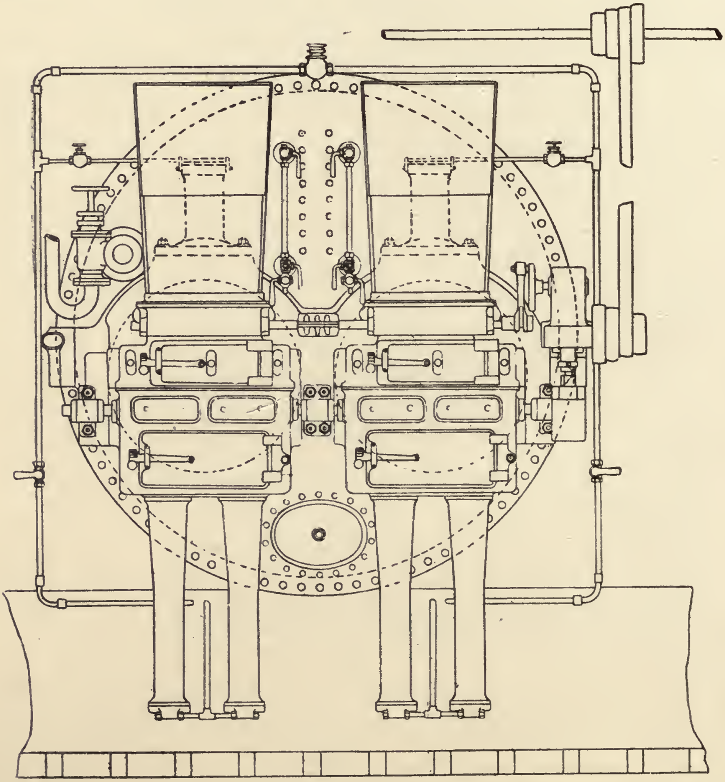


FIG. 22.—Front elevation of "Koker" Stoker.

The view in Fig. 22 shows the application of this stoker to a Lancashire boiler. It will be seen that below the front casing of this stoker, which is not unlike that of other makes in general appearance, are four circular pipes coming upwards from the floor. These are the blower pipes, in which the currents of air are led beneath the furnace bars, after being induced by the steam jets. By having a closed ashpit in this way, and maintaining in it an air pressure, and at the same time using fire bars between which the spaces are very small, cheap, small coal can be used, the combustion can be forced, and the evaporation very much increased.

With regard to the mechanical details, the makers contend that the ram or pusher working on a pivot requires much less power to work it than is necessary with the sliding ram used in many stokers of this kind, and that the arrangement for adjusting the rate of feed has the advantage that it can be increased or diminished without stopping the machine. Another point which is emphasised is that the bars and cams are so designed as to have fully double the usual wearing surfaces, which gives them greatly increased life.

A distinct feature of this stoker is the fact that two sets of blowers are used, one below as described and the other above the fire. These latter drive the air vertically downwards behind the fuel hopper, whence it passes into a space between the fire door and a grid forming the front of the grate, provided with small narrow openings between vertical bars. This admission of forced air behind the heap of green fuel very greatly assists the coking and makes it more certain. The air pressure below the bars varies from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inch of water by the gauge. The pressure of the top jets is generally arranged so as to be slightly greater than that below the bars.

The bars themselves carry the fuel forward in the usual way, but, instead of being given a slight vertical motion as well as a longitudinal one, as in some other cases, the top edges of the bars are made wavy, with the crests of the one bar coming opposite to the troughs of the next. By this device the bar movement is made simpler and less expensive, and, at the same time, it is quite impossible for clinkers to become attached to the bars. A section is shown in Fig. 23.

Several full efficiency tests of boilers fitted with these stokers have been made, and the following figures, which have been extracted from the results of these, are instructive as regards the working of this form of mechanical stoker :—

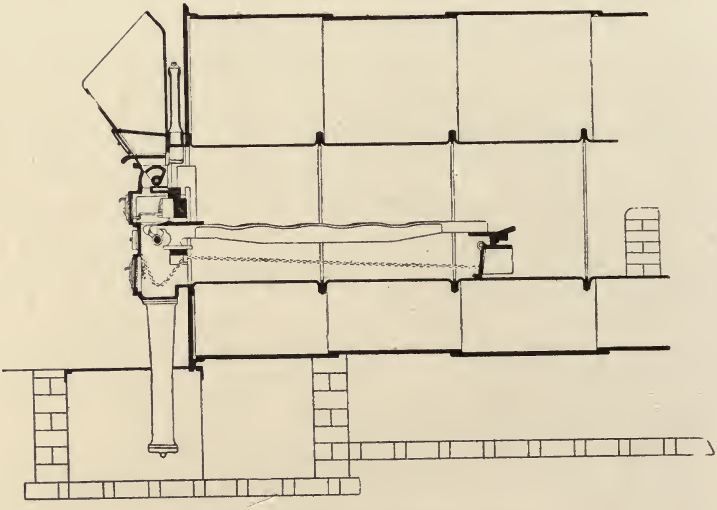


FIG. 23.—Section of "Koker" Stoker.

AVERAGE RESULTS OF TESTS WITH "KOKER" STOKERS.
(The duration of each test was eight hours continuous running.)

	8 foot Lancashire boiler. (Average of three tests.)	7 ft. 6 in. Lancashire boiler. (Average of two tests.)	7 ft. 6 in. Lancashire boiler. (Average of three tests.)
Kind of coal used . .	Nuts and slack.	Nuts at 7s. 10d.	Slack at 6s. 9d.
Water evaporated per sq. ft. heating surface per hour	10·58 lb.	9·40 lb.	9·69 lb.
Water evaporated at and from 212° per hour per lb. of coal	9·34 lb.	10·88 lb.	10·61 lb.
Mean pressure in boiler .	69·6 lb.	61·0 lb.	62·0 lb.
Weight of coal burnt per hour per sq. ft. of grate	37·25 lb.	28·40 lb.	29·60 lb.
Percentage of heat transferred to boiler (effic.) .	64·25 per cent.	69·70 per cent.	72·74 per cent.
Percentage of CO_2 in flue gases	11·9 per cent.	12·0 per cent.	12·4 per cent.

In all cases absolutely no smoke was made during the tests.

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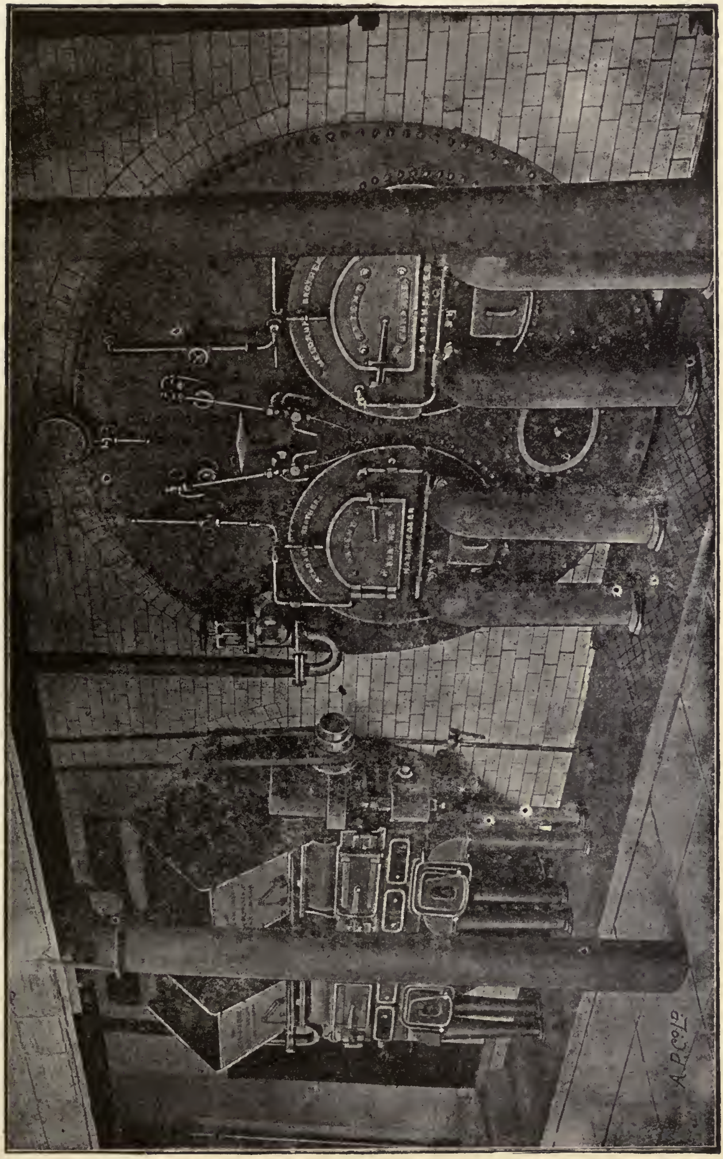


FIG. 24.—"Koker" Stokers on Lancashire Boilers.

The following are some more recent figures obtained from tests of "Koker" stokers. Several figures are given here which do not occur in those above:—

Test of a Lancashire boiler, 34 *feet by* 7 *feet* 6 *inches,* fitted with "Koker" stoker, with forced draught (April, 1900):—

Duration of trial	6 hours
Grate area in square feet	36
Mean steam pressure, pounds per square inch	62
Water evaporated per lb. of coal at and from 212°	9·8 lb.
CO_2 in flue gases	14·16

The fuel was White Moss slack.

It will be noticed that the percentage of CO_2 is high. This was obtained purposely in order to render the gases suitable for use in a chemical process.

Test of a Lancashire boiler, 30 *feet by* 8 *feet,* fitted with "Koker" stoker and forced draught:—

Duration of trial	8 hours
Grate area in square feet	35·75
Average evaporation per hour in gallons	1112·5
Fuel fired per square foot of grate per hour	44·7
Evaporation per pound of fuel (actual)	7·11
Average pressure in ashpits	2 in. water
Average pressure above the fires	¾ in. water
Average steam pressure in pounds per sq. in.	97

The kind of fuel used was Durham rough slack.

Test of a Lancashire boiler, 24 *feet by* 8 *feet,* fitted with "Koker" stoker and forced draught:—

Duration of test	7 hours
Average evaporation per hour	10,090 lb.
Fuel fired per square foot of grate per hour	39·27
Evaporation per pound of fuel (actual) in pounds	7·17

The kind of fuel used in this test was Durham rough small at 16s. per ton delivered.

Messrs. Meldrum also say that this stoker is in successful operation burning ordinary gasworks breeze, with very little

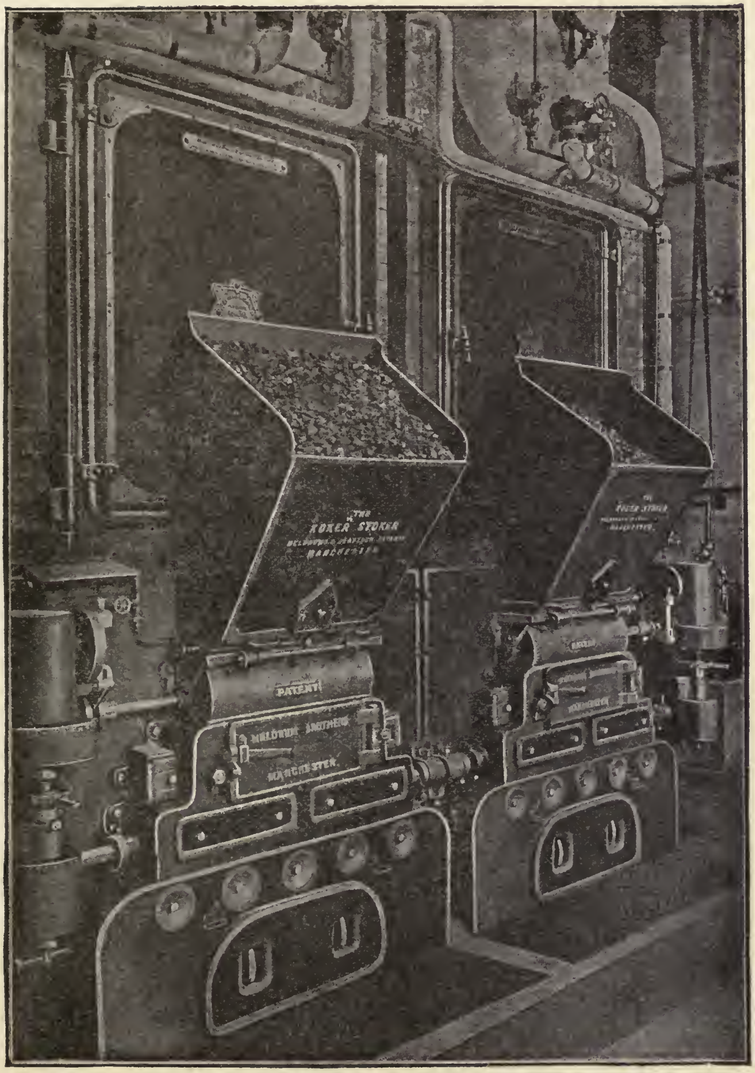


FIG. 25.—Application of "Koker" Stoker to Babcock Boilers.

trouble in attention and cleaning out. In one case a "Koker" stoker is fitted to one of a range of boilers and burns up the

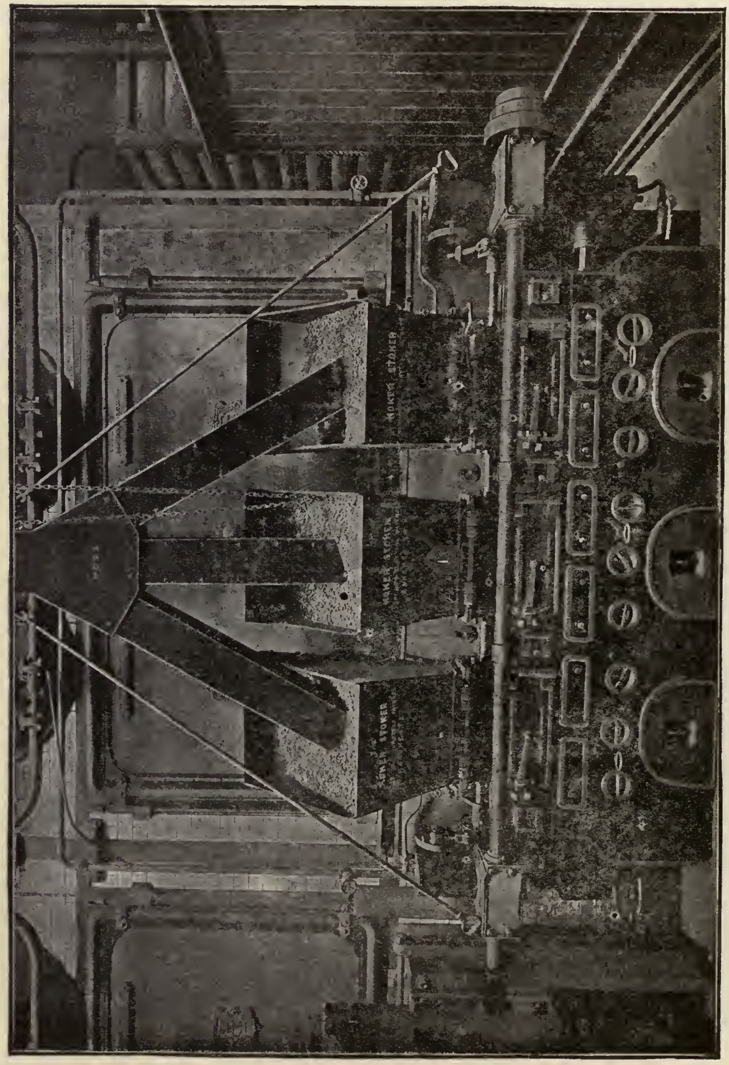


FIG. 26.—"Koker" Stokers on Babcock Boilers

cinders that fall through the bars of the remaining mechanical stokers with which the other boilers are fitted, there being a certain amount of unburnt fuel in the cinders which it is found worth while to make use of in this way.

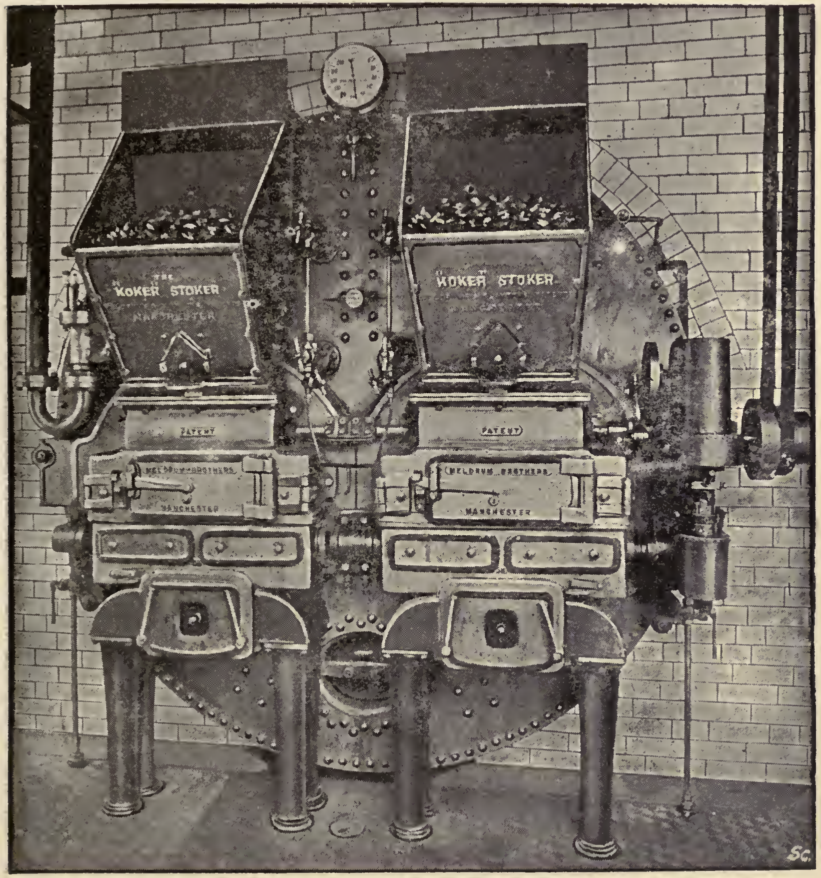


Fig. 27.—"Koker" Stokers on Lancashire Boiler.

In Figs. 24, 25, 26 and 27 are shown photo views of Meldrum's "Koker" mechanical stoker.

JUCKES' FURNACE.

This is in reality a coking stoker, built on rather original lines. A sectional view of the furnace, when applied to a brewer's copper, is shown in Fig. 28. It will be seen that the whole of the grate is supported on a movable truck or trolley; the object of this arrangement being to make it easy to take the grate out of its place for purposes of inspection and repair. The manner of working is as follows: A hopper is provided at the front of the furnace, marked S in the figure, and into this is thrown the fuel which is to be burned. The extent of the feed can be regulated by a hand wheel, marked O in the figure. The fuel falls from the hopper on to the grate bars immediately at the front end of the grate. The novel feature of this device lies in the arrangement of the grate bars themselves. These are simply a number of bars or links so jointed together as to form a broad, flat, endless band, which passes round two drums or tumblers at the ends of the truck, as will be seen in the illustration. By means of the belt-driven mechanism at the front of the furnace, this band, which forms the grate, is kept in continual motion, the top surface always moving from the front towards the back. The speed of the grate bars can be varied from fifteen to twenty feet per hour, as may be wished.

It will be seen that this grate is simply a coking stoker, in which the backward movement of the fuel is obtained by a continuous movement of bars in the form of an endless chain, instead of by means of a reciprocating motion, as in the case of most other coking stokers. This furnace has been applied to steam boilers in much the same way as shown. It can also be used for burning refuse and very small stuff. Like other coking stokers of the more usual form, this furnace would probably be unsuitable for use under a boiler whose work is intermittent, and is most suitable for steady and uniform work.

This furnace is said to be perfectly smokeless.

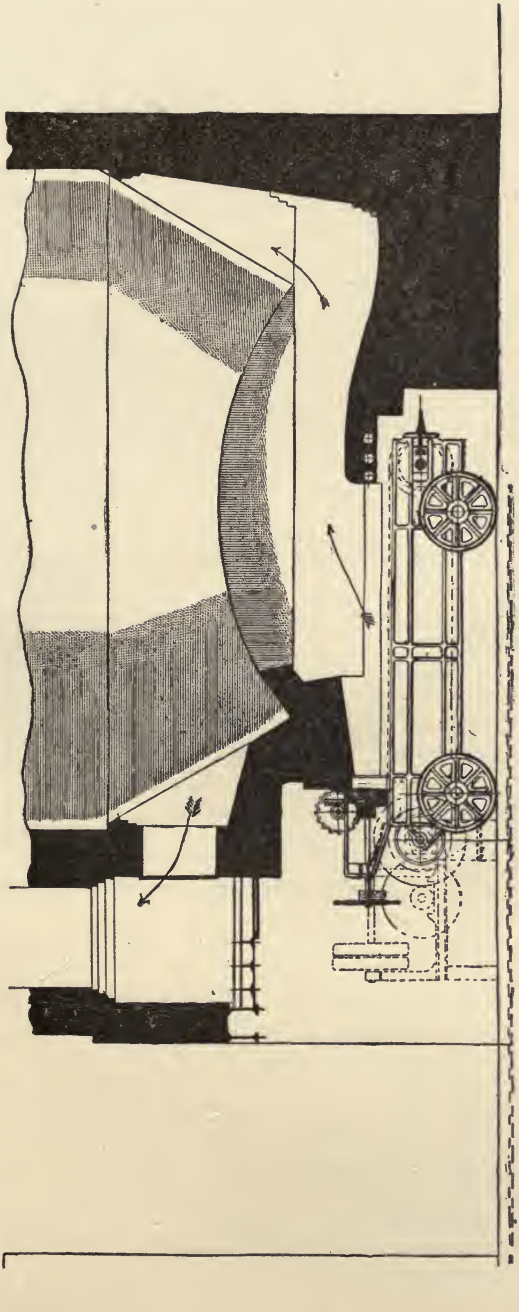


FIG. 28.—Juckes' Mechanical Stoker fitted to a Brewer's Copper.

THE MURPHY FURNACE.

This furnace, which is very largely in use in the United States, has been recently introduced to this country, and promises to give very good results when applied to any kind of boiler, both as regards economy and smokelessness. It is a mechanical stoker differing in many important points from any of the mechanical stokers of the ordinary type in use in this country. It is said to be especially adapted for use with small sized bituminous coal and slack. The furnace itself is enclosed in brickwork with an iron front, and is placed externally to the boiler to which it is applied in the case of tubular and internal flue boilers, and underneath in the case of water-tube boilers,

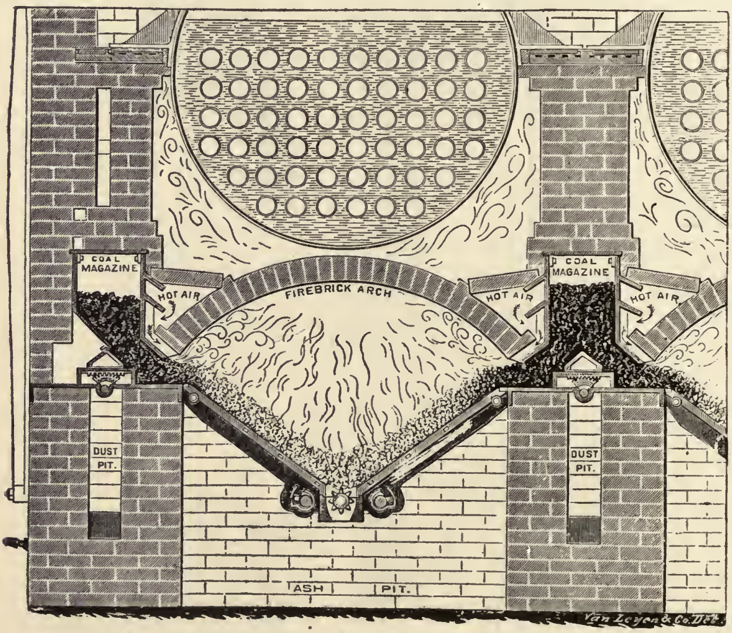


FIG. 29.—Cross section of Murphy Furnace.

such as the Babcock and Wilcox. A good idea of the general arrangement of this boiler will be obtained by an inspection of Fig. 29, which represents a transverse section through the furnace, which, in this case, is applied to a horizontal tubular boiler. It will be seen that the bars, of which a side view is obtained, are set at an angle of about forty degrees with the horizontal, in two sets, each of which slopes down towards the centre, where there is an opening, through which the ash and clinker are allowed to escape. At the top of each slope is a fuel magazine, running the whole length of the furnace, and into which the fresh fuel is fed. At the bottom of each of these magazines there is a casting, forming the coking plate, against which the tops of the grate bars rest. On this coking plate rests a box, which has a reciprocating motion, the movement being given to it by means of a pinion and rack. The speed of this movement can be regulated to suit the speed of combustion which is desired. As the box moves forward it pushes some of the fuel resting on the plate, having fallen there from the magazine. As the fuel rests on the bottom of the magazine, which is formed partly by the coking plate and partly by the pusher box, the heat at that point is sufficient to start the coking process, and the hydrocarbons begin to come off from the coal at once. The effect of the movement of the pusher is to deliver at each stroke some of this partly coked coal on to the higher ends of the grate bars. Immediately over the coking plate is the arch plate on which rests the end of the firebrick arch, forming the top of the furnace. Where the firebrick comes in contact with the arch plate, ribs are provided an inch apart, forming the skew-back on which the arch rests. The spaces formed by these ribs are air passages. The air is admitted and allowed to pass over the arch in flues, and, on its way, takes up heat from the front, arch, and arch plate, and, passing downwards through the openings as shown, provides the oxygen necessary for the proper combustion of the volatile gases. An addition to the economy is produced by reason of the heating of this air before it is admitted. It is to be noted that this admission of the heated air to the hydrocarbons as they come off from the fuel is one of the causes of the smokelessness of this furnace. The air supply can be regulated to a nicety, and just sufficient admitted at all points along the line formed by the top ends of the bars as is necessary for perfect combustion and absolute freedom from smoke. By the time that the pusher plate has caused the fuel to reach the fire bars, all the gaseous part of the fuel has been driven off and burnt, and what remains is unconsumed carbon,

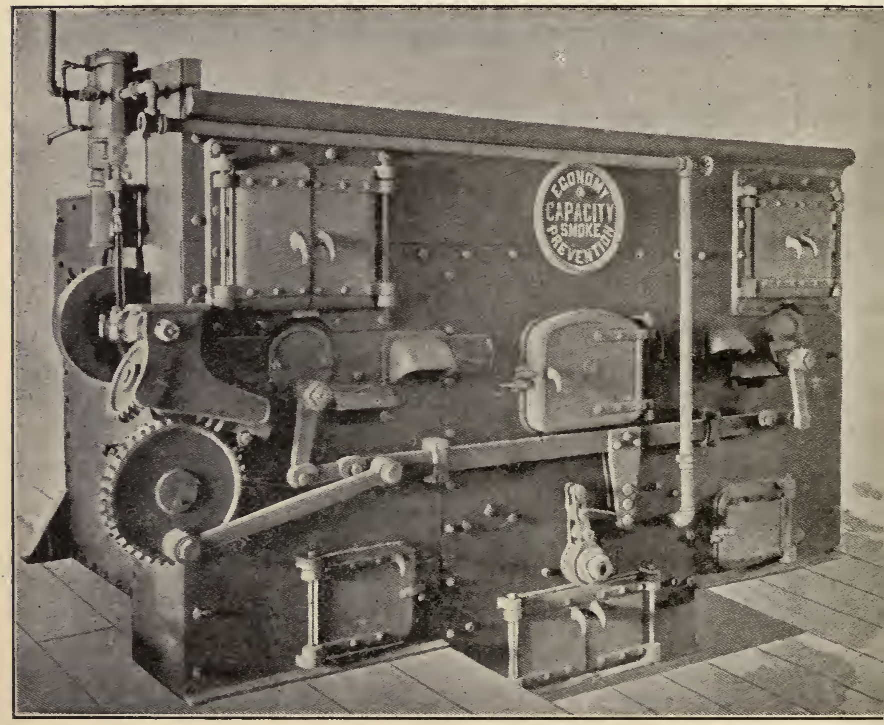


Fig. 30.—General view of Murphy Furnace.

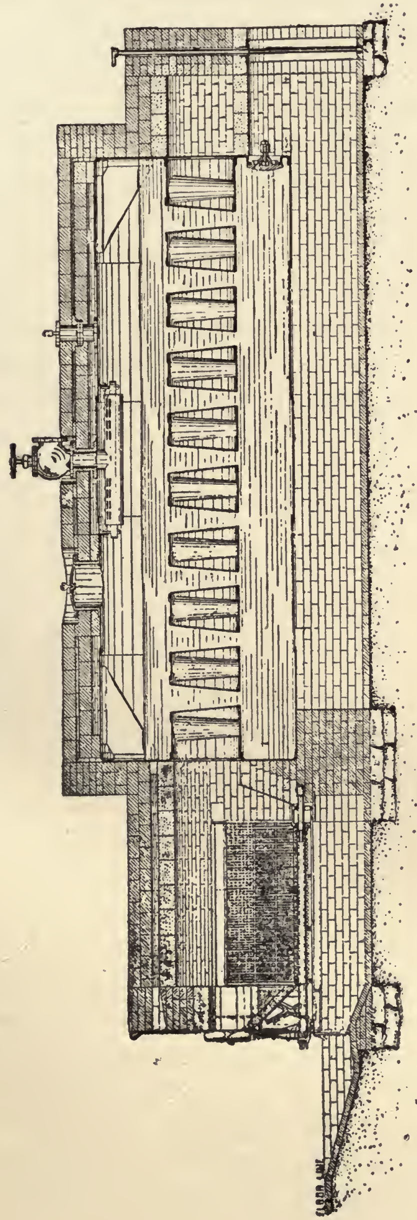


Fig. 31.—Application of Murphy Furnace to Galloway Boiler.

whose combustion is smokeless. The necessary quantity of air for burning the coke passes up through the bars in the usual way. The grate bars are kept constantly in motion by means of a small steam engine, and the burning fuel is gradually worked downwards, and reaches the bottom of the bars as ash and clinker. The latter is broken up by an automatic breaker, consisting of a slowly revolving shaft studded with teeth. All the mechanical motions are derived from a reciprocating bar on the outside of the furnace front, and this is so arranged that any one motion can be disconnected from the automatic bar and worked by hand. Fig. 30 gives a general view of the outside front of this furnace, and Fig. 31 shows it applied to a Galloway boiler.

As a result of some very complete tests by Professor Ripper, of Sheffield, the following are some of the general conclusions deduced:—

1. The furnace is capable of burning the cheapest coal smokelessly.
2. The prevention of smoke is due to the following special points of construction:—
    - (*a*) The length of the opening through which the green coal is fed to the furnace is more than five times that available with the usual arrangement of furnace, thereby spreading the fresh coal over a large area in a thin layer.
    - (*b*) The combination with the above of a mass of hot brickwork, and a hot air supply at the point where the smoke-making gases are being distilled off from the green coal, thus securing complete combustion.
3. The adoption of inclined bars increases the effective area of the grate by 25 per cent. over that of the horizontal fire, hence the capacity of the furnace for steam raising is considerably increased.
4. The automatic removal of clinker and ash saves labour,

and obviates the necessity of opening the furnace doors for its removal.

5. The labour attending the furnace is small.
6. The cost of evaporating 1,000 lb. of water, with fuel at 3s. 6d. per ton (the price of the fuel used in this furnace for these tests), is 2¾d., which, reckoning 30 lb. of steam per I.H.P. per hour, is equivalent to 12 H.P. per 1d.

The above are a few of the conclusions expressed in Professor Ripper's own words as they stand in his report, and may be taken as distinctly favourable to this furnace, both as a smoke burner and non-emitter of smoke, and also as an economical furnace, capable of using the cheapest kind of fuel.

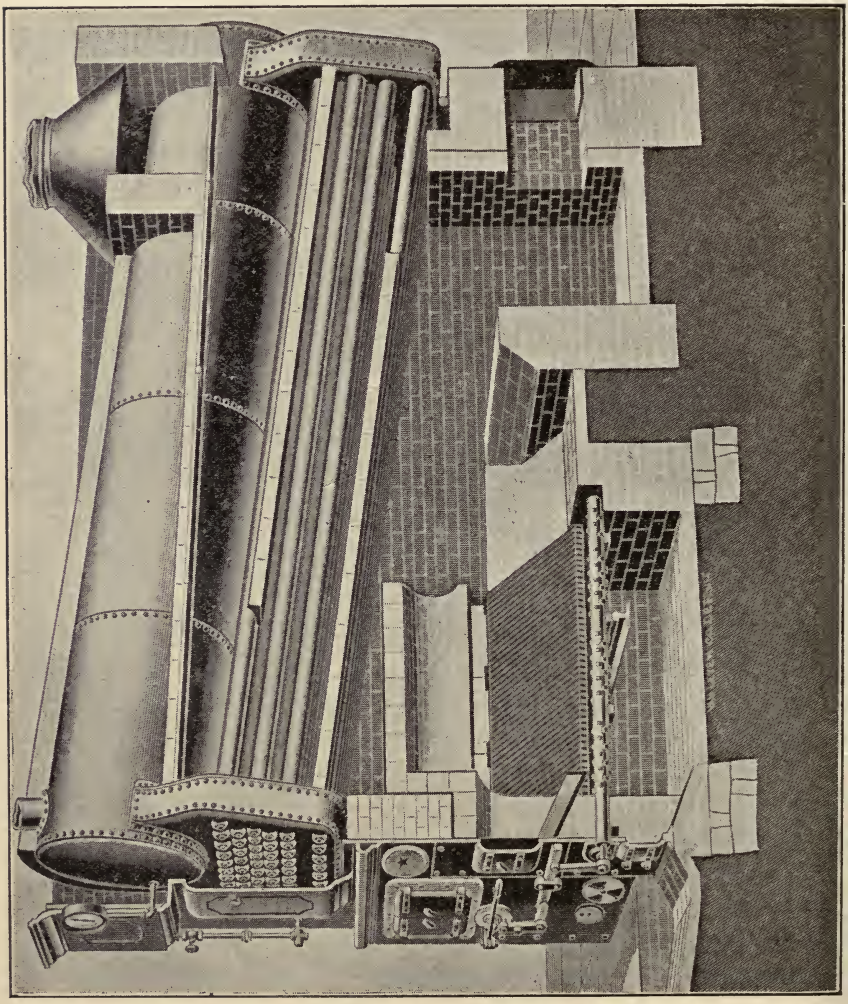
It will probably be found that the chief objection raised to the adoption of the furnace in this country will be that owners of boilers will be reluctant to go to the expense and trouble of building a furnace which is quite external to the boiler. This, of course, would not apply to boilers of all types.

Application of the Murphy Furnace to a Water-tube Boiler.

In Fig. 32 is shown a view of a Murphy furnace as applied to a water-tube boiler. This illustration, besides showing the application to this particular kind of boiler, serves to give a very good idea of the internal appearance of the grate. The makers of the furnace, Messrs. Donkin & Clench, consider that the Murphy furnace is most suitable for boilers of this kind, there being no necessity in such cases to build a special casing for the furnace outside the boiler.

Underfed Mechanical Stoker.

A stoker made by the Underfed Stoker Company has been recently introduced, and is said to be meeting with a considerable amount of success. The fire bars form two flat slopes rising upwards towards the centre of the grate. The general shape is not unlike that of a ship's skylight. The bars are flat and lie in position similarly to the slates of a roof, except



that there is a space between each pair of bars through which the air can pass upwards from the ashpit below the fire. Small coal is fed into a hopper, which is necessarily placed low down on the front of the boiler. The fuel falls direct on to the back end of a conveyer worm at the bottom of the hopper. This worm is conical in shape, decreasing towards the back of the grate, the pitch decreasing also. It lies in a conical space below the centre of the grate. The coal is carried along, and is made to rise upwards through a longitudinal slit which traverses the whole length of the grate in its centre. The graduated diameter and pitch of the worm cause the coal to rise uniformly throughout the whole length of the grate. As the fuel rises to the centre of the grate the heat starts the coking action, the volatile gases pass upwards through the incandescent fire, and are mixed with the air which is forced upwards by a fan between the bars. As combustion proceeds the coked fuel falls down the bars to the ash trough at the side, where all the unburnt incombustible matter in the fuel is deposited. The worm is rotated and a slight lateral movement given to the bars by mechanical means. *This furnace is said to be smokeless in its working.*

General Conclusions with Regard to Mechanical Stokers.

It must not be supposed that mechanical stokers are equally applicable to all cases. Where the plant is large, and the number of boilers large also, a system of mechanical stoking may be expected to yield the best results. Generally speaking, cheaper coal can be used in a machine stoker than is the case with hand-firing without forced draught, and in this direction a considerable saving can often be effected. Then, again, in a large installation it is possible to arrange for some general system by which the hoppers of the stokers can be supplied without the necessity of shovelling by hand, and in this also a large saving of labour can be attained. Less attention is required than is the case with hand-fired furnaces, because a great part of the feeding is done automatically; though, at the same time, a certain amount of attention is needed for such purposes as seeing that the air supply is properly adjusted, regulation of the feed, cleaning out the ashpit, and general supervision of the mechanism. In Mr. Hales' report, which is given in a later chapter, some important figures will be found, giving the amount of labour required under certain conditions.

Where the installation is small it will not in most cases pay to use a mechanical stoker, unless it is one of the forced draught type. If there is difficulty in avoiding smoke with hand-firing, then a coking mechanical stoker will be found useful.

Regarding the respective advantages of sprinklers and cokers, the facts are briefly these:—

A sprinkling stoker will as a rule produce more steam than a coker, and can be used to force the boiler somewhat, but most sprinklers are productive of smoke. Cokers, on the other hand, are much less capable of being forced, and will not readily yield to fluctuations in the demand for steam, but they are smokeless in their working, which is of great importance.

For large plants and for uniform steaming there is no doubt that coking mechanical stokers provide the most satisfactory method of firing from all points of view, and, probably, those which are combined with forced draught and which have a partial sprinkler arrangement in addition to the movable bars are the best. From a smoke point of view the Murphy furnace is perfect, but it has the inherent disadvantages which have been mentioned, but which may be overcome in the future.

CHAPTER IV.

POWDERED FUEL FIRING.

MANY attempts have been made to perfect a method of supplying the coal to a boiler furnace in a finely divided condition. By feeding the coal in this way an ideal state of things is attained, each particle of coal being very small, and surrounded by just enough air to totally consume it. The air supply can be so regulated as to give exactly the necessary amount of oxygen, and no more, and at the same time no smoke need be produced and no unburnt CO sent up the chimney.

The first to attempt this burning of dust fuel was Crampton, who worked persistently at it from 1868 to 1873, and, after spending a large sum of money on the experiments, failed to attain any lasting success. Crampton ground his coal and drove it into the combustion chamber by means of a blast. His chief difficulty appears to have been failure to obtain a satisfactory refractory substance with which to line the furnace; the temperatures attained were extremely high, for the reason that the heat generated by each particle of coal is concentrated in the CO_2 resulting from combustion and the nitrogen, and there is little carried away by excess oxygen.

THE WEGENER SYSTEM OF POWDER FUEL FIRING.

During the last ten years several systems have been brought out and used, chiefly in Germany, for the utilisation of fuel in the form of finely divided powder. Of these one of the earliest to be used was the Wegener device, and this was followed by the Schwartzkopf and the Friedeburg processes. The process used by Wegener is not an elaborate one. Briefly it is this:—

Powdered coal, or other fuel which is capable of being reduced to powder, is brought in sacks to the furnace, and each sack as it is required is emptied into a large hopper, at the conical bottom of which is a screen with about a 60-to-the-inch mesh. This sieve is being constantly shaken by an automatic agitator, which is worked from a fan in the air trunk, so that there is no tendency for the powder to get clogged on the sieve. After passing through the sieve the powder falls towards the upcast air trunk, where it meets the current of air, in which it is carried or floated round a right-angled bend, and in a horizontal direction, into the boiler furnace. When applied to a Lancashire or Cornish boiler the mixed air and coal are carried into the flue tube through a circular pipe about

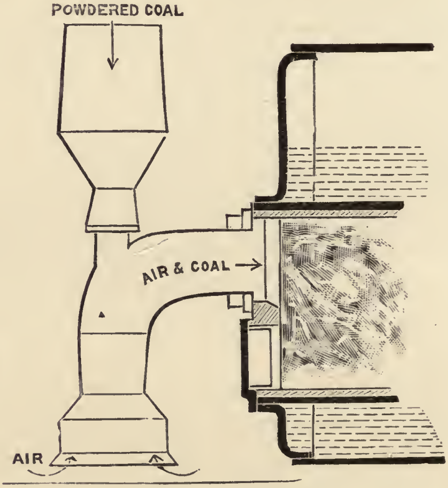


FIG. 33.—The Wegener System of burning Powdered Coal.

nine or ten inches diameter, entering the flue near the top. The flue is lined with fireclay to a thickness of an inch, and for several feet inwards, the object of this lining being to provide an incandescent surface to promote combustion, and at the same time to protect the interior of the flues from the intense heat generated during combustion. An extra air supply is provided near the point where the fuel and air enter the furnace. This air supply can be regulated at will, as also can the main air current which meets the falling powder. The cost of powdering the coal, which can be effected in any kind of disintegrator or pulveriser, is stated to be about ten per cent. of the cost of the coal, which may be said to compensate for the reduced price of the kind of coal which can be made use of.

In the case of an installation of this kind in use at the Bermondsey Works a saving of twenty per cent. is reported to be effected over ordinary hand firing.

A diagrammatic sketch of this arrangement is shown in Fig. 33.

WHELPLEY AND STORER'S SYSTEM.

This system, in use in the United States in the early eighties, has met with a considerable amount of success, more especially in connection with metallurgical work. The manner of introducing the coal into the furnace is somewhat similar to that of the Wegener system, but instead of grinding the coal and then sending it into the furnace by means of a separate arrangement, the grinding and feeding are done in one operation. A machine, called an atomiser, is placed just above the front of the furnace, and receives the coal, preferably in the form of coarse slack. This enters a hopper, from which it is supplied by means of a revolving feed arrangement into the first atomising chamber. In this chamber six flat beaters revolve at a high speed, and the coal is reduced to smaller pieces by striking against fixed ribs on the inside of the chamber, as it is carried round by the rotary current of air, and also by the mutual attrition of the pieces of coal. Near the centre of this first chamber is an opening leading into the second chamber, and the smaller and lighter particles are carried into this by the current of air as it passes through the machine. In this way the coal is gradually reduced in size by passing through two or more chambers, until it reaches the last, in which the beaters act as fan blades and deliver the fine dust to the furnace by floating it in with a current of air, each particle being surrounded by an enclosing envelope of air. Between the last grinding chamber and the fan chamber is a fine wire screen, which prevents any but the smallest particles from passing through.

When the coal dust leaves the machine it passes along a short cast-iron pipe, which is circular to start with, but is flattened out at the furnace end to a long horizontal slit, about $\frac{5}{8}$ of an inch wide and 12 inches long for a 2 foot 9 inch flue of a Lancashire boiler. Out of this pipe the fuel enters the furnace, the pipe at this point being surrounded with a water jacket to prevent burning.

The combustion chamber itself is circular or elliptical in section and slightly reduced in section at its back end, like the mouth of a Bessemer converter. It is lined with firebrick, and provided at its front end with a fire grate placed below but opening into it, in order to heat the inside of the chamber when the furnace has to be started.

A sectional view of a furnace after this pattern, designed by the writer, is shown in Fig. 34.

Before the burning of the dust fuel can take place a fire must be lit on the grate, and kept going for a short time in order to render the interior of the combustion chamber sufficiently incandescent to ignite the dust as it enters. When this is done, the machine is started, and the coal floated in; ignition immediately takes place, and the whole of the combustion chamber is filled with a mass of flame, produced by the burning of the gases of the coal and by the incandescent carbon. The only products of combustion are the resulting gases and the diluting nitrogen, and there is not, as in the case of an ordinary open furnace, a large quantity of heat carried away up the chimney by the excess air which has to be admitted in that case.

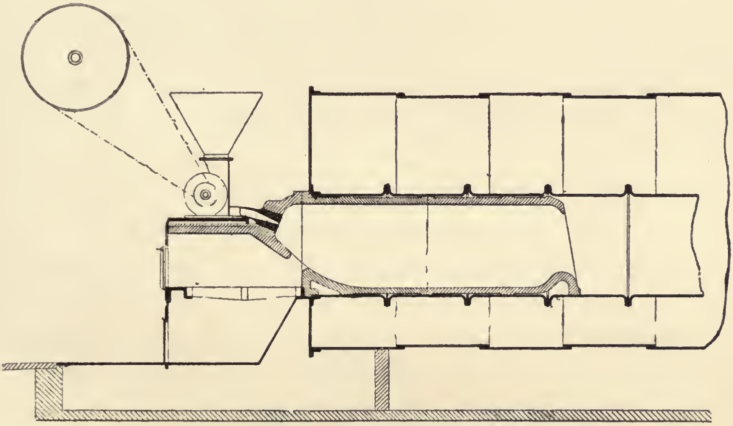


Fig. 34.—Dust-fuel Furnace.

Some years ago the author took part in a number of experiments on the firing of furnaces on this system. The method was applied to an open reverberatory furnace, and also to a two-flued Lancashire boiler. The following conclusions were drawn from these tests:—

1. The combustion of the coal in a long open firebrick furnace was exceedingly good, a perfectly even, uniform white-hot flame being produced, the temperature being somewhere in the neighbourhood of 2,700° Fahr.
2. The flame was from twenty to thirty feet in length.

3. By properly adjusting the supply of air and coal, absolute freedom from smoke resulted.

Owing to faulty design of the combustion chambers, the experiments on the boiler were not so successful, and further experiments were abandoned.

Experiments in America would seem, however, to have been more successful in the application of dust fuel for the purpose of raising steam. The boilers used in America were mostly externally fired boilers, and a larger incandescent surface was provided for the purpose of maintaining the combustion.

It is evident that this burning of coal in the form of dust has two distinct advantages over the old method of combustion. In the first place, a cheaper kind of coal can be made use of than heretofore; secondly, the conditions result in a higher temperature in the furnace; and, consequently, a larger amount of heat transmission, and there is less waste heat carried away in the flue gases.

Against these must be reckoned several disadvantages. The author found that with damp or bituminous coal the passages and the machine had a tendency to become clogged, the power required to drive the machine was considerable, and must be reckoned against any saving effected. It is a distinct disadvantage to have to bring the combustion chamber to a state of incandescence before starting the feeding; the wear and tear on the boiler will probably be greater than with ordinary hand or machine firing; and the dust from the gases accumulates, and is a source of trouble.

Probably the most successful working of a system of dust fuel firing would be where there were a large number of boilers working continuously or nearly so.

CHAPTER V.

GASEOUS FUEL.

Gaseous fuels are of three kinds: namely, natural gases, such as those found at Pittsburgh; producer gas, made by passing air or air and steam through burning fuel; and bye-product gases, resulting as waste products from special processes, such as coke-making and the destruction of refuse.

Siemens and Wilson Gas Producers.

These, among the earliest gas producers, are made to yield a combustible gas by allowing a current of air, moistened by steam, to rise through the incandescent coke left from the distillation of the coal supplied; the coal is fed in near the top of the producer, and the hydrocarbons are driven off from the green fuel by means of the heat generated by the imperfect combustion or oxidation of the carbon going on in the lower layers of the fuel. The CO and H produced by this action of the air and steam on the incandescent coke are mixed with the hydrocarbon gases, and the mixture is the producer gas required. For some purposes this gas may be used at once in its original state, but for other uses, such as for gas engines, it is absolutely necessary for all tarry matter to be eliminated. The gas generated in these producers may be carried to boiler or other furnaces, and burned directly, the chief requisite being a careful attention to the air supply in order that the whole of the combustible matter may be consumed, and, at the same time, there may be a minimum of waste heat carried away by excess air and nitrogen.

DOWSON PRODUCER GAS.

This gas is primarily intended for use in gas engines, and for that reason only coke, charcoal or anthracite coal are used, in order that there may be no tarry matter in the gas. The Dowson producer has open grate bars at the bottom, and a draught of air is carried upwards through the incandescent fuel with superheated steam, which is supplied from a small auxiliary boiler. The oxygen of the air and steam combine with the carbon of the fuel to form CO, which passes upwards and leaves the producer along with the hydrogen from the steam, the two together forming the Dowson Gas. This gas has been very largely used, especially for gas engine work. It is also used for a great number of cases where heat is required for specific purposes in an easily controllable form, such as minor metallurgical operations, baking, laundry work, etc. For use in boiler furnaces it has not so far been found that there is any economy to be gained by burning gas in the place of solid fuel, though the combustion is perfectly smokeless.

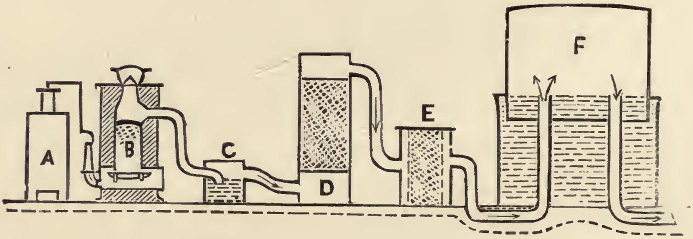


FIG. 35.—Dowson Gas Plant.

On Fig. 35 is shown a diagrammatic sketch of a Dowson generating plant. Beginning at the left hand side of this sketch and proceeding to the right the whole process can be followed out in the proper sequence of stages. The steam boiler used for generating the superheated steam is marked A. This steam is shown as coming into the bottom of the generator, B, below the grate bars. The steam and a little air pass upwards through the incandescent zone in the generator, along the pipe shown to the hydraulic box, C, where the tar is removed from the gas. From here the gas is passed through two other cleaners, namely, the coke scrubber, D, and the sawdust scrubber, E, whence it is taken into the gas holder, F. The writer is indebted for this sketch to a paper by Mr. Dowson on "Gas Power," read before the Cleveland Institution of Engineers.

It is also stated in this paper that from 1877 to 1897 there were sold by the Gasmotoren Fabric of Deutz, and by Messrs. Crossley Brothers, of Manchester, a total of 62,961 gas engines, having a collective brake horse power of 521,652. Also during 1898 Messrs. Crossley alone sold 2,971 engines. These figures convey a very definite idea of the large number of gas engines that are now being used in place of small steam engines. Of course these figures do not include the large number of engines made by other firms. Apart from other conditions, the cost of running a gas engine of small power, say twenty horse power, with ordinary illuminating gas is greater than that of a steam engine of equal power, but there are many points of convenience which make a gas engine preferable to a steam engine for small powers. If, however, the power required is large, and a plant is laid down for generating a cheap gas from coke or coal, the advantage is on the side of the gas engine. Mr. Dowson gives the total efficiency of a steam engine plant under what he calls the "practical best" conditions as 10·5 per cent., and for the "practical average" as only 5 per cent.; on the other hand, the corresponding figures for a gas engine are respectively 24·6 and 15 per cent., showing that, regarded as a heat engine, the gas engine has much the greater advantage.

At the present time gas engines are being made to work with generator gas for powers up to some hundreds of horse power, and this mode of working may be expected to greatly increase during the next few years.

KÖRTING'S PRODUCERS.

In these, blowers are used, consisting of steam jets carrying into the fuel large quantities of air at a low pressure. The bottoms of the producers are closed, and the steam and air are blown in at one or more places. By this arrangement the quantity of gas produced in a given time is much greater than in the case of open bottom producers. By making the producer sufficiently high the amount of CO_2 produced may be reduced to a minimum.

COKE-OVEN GAS.

The old-fashioned method of making coke is rapidly giving place to more economical methods. In the old beehive coke-oven—which is still largely used—the carbonisation is effected by allowing a little air to penetrate the interior of the oven, and the combustion effected by this air is sufficient to effect the volatilisation of the remaining hydrocarbons. In ovens of this type the hydrocarbons, as they are driven off, are allowed to escape into the atmosphere, where they burn with a luminous flame, and all the heat so generated is wasted. In the more modern ovens the coking is effected in closed retorts, the only openings being those through which the hydrocarbons escape as they are driven off. These gases are carried away in a hydraulic main, in which the tar is deposited. The oils in the gases are also recovered, as well as the ammonia, by passing the gas through scrubbers. The purified gas can now be used, some of it to be burned under the retorts, in order to drive off the hydrocarbons, and the remainder may be burned under boilers in order to raise steam. The writer recently inspected a coke plant of this kind. Excellent coke was produced, a large amount of tar and ammonia was recovered, and sufficient heat developed to raise the steam necessary for driving the engines and pumps used in the process. Of course it is hardly necessary to say that the chimney was smokeless, except during the few minutes in which the ovens were being fed.

The following analyses of coke-oven gases have been kindly supplied to the writer by Mr. F. Grover, of Leeds. They were taken from ovens of the ordinary beehive type under slightly different conditions of working.

TABLE V.—ANALYSES OF COKE-OVEN GASES.

Hours oven had been burning when sample was taken.	Constituents.				Per cent. combustible matter.	Cal. val. per cubic foot.	
	CO_2	CO	H	N			
90	13·2	1·1	4·8	80·9	5·8	17	Foundry Coke
60	14·3	12·0	6·3	67·4	18·3	58	
52	9·8	7·5	12·7	70·0	20·2	62	
48	9·0	5·2	13·7	72·1	18·9	57	
18	7·9	4·7	21·0	66·4	25·7	77	
18	8·7	15·6	26·0	49·1	42·2	128	Steel Coke
10	3·2	2·8	14·6	79·4	17·4	50	

The figures in the seventh column refer to the number of thermal units given out by the perfect combustion of one cubic foot of the gas at the normal pressure and temperature.

WATER GAS.

The gas produced by sending steam through incandescent coke is called water gas, and may be used as a gaseous fuel. It consists of about equal proportions of carbon monoxide and hydrogen, and a little nitrogen and carbon dioxide.

Blast Furnace Gas.

A combustible gas is sent off from the top of blast furnaces, and may be made use of for any purpose where a gaseous fuel is required. Its composition is given in the following table.

Gas from Refuse Destructors.

At the present time refuse destructors are being largely used for the purpose of burning town rubbish, and the gas given off from the heated refuse is a combustible gas, which in some systems is taken, by means of a pipe, and burned under the retorts or cells with the addition of a secondary air supply. The gas is not a rich one, but is sufficient for the purpose. In many cases, also after combustion, the flue gases are taken under boilers for the purpose of raising steam.

The following are some analyses of gaseous fuels :—

TABLE VI.—TABLE OF ANALYSES OF GASEOUS FUELS.

Gas.	H	CH_4, etc.	CO	N	CO_2	Combustible Gases.	Air required per cub. foot.	Authority.
Pittsburgh natural gas . . .	22·0	67·0	0·6	3·0	0·6	95·6	8·06	Humphrey
Illuminating coal gas . . .	49·0	39·5	7·5	0·5	0·0	98·8	5·81	Humphrey
Siemens closed hearth . .	8·6	2·4	24·4	59·4	5·2	35·4	—	—
Siemens closed hearth . .	19·43	2·66	16·15	50·23	11·53	38·24	—	Sexton
Wilson . . .	11·55	1·45	26·89	56·11	4·0	39·89	—	—
Dowson . .	18·73	0·6	25·07	49·01	6·57	44·42	1·132	Thorpe
Solvay coke-oven gas . . .	56·9	22·6	8·7	5·8	3·0	91·2	4·10	Humphrey
Strong water gas .	52·76	6·11	35·88	4·43	2·05	62·75	—	Moore
Blast furnace gas, coal fed . .	3·68	3·62	27·5	59·27	6·15	34·80	—	Archibald
Blast furnace gas, coke fed . .	2·74	0·2	28·61	57·06	11·39	31·55	—	Fowler
Mason's destructor	13·6	1·6	10·0	59·21	3·0	25·20	—	Fowler
Mond gas . .	24·8	2·3	13·2	46·8	12·9	40·30	1·24	Humphrey

THE PRODUCTION AND USE OF MOND GAS.

Before the introduction of the Mond process of generating producer gas, in no case had a successful attempt been made to recover any of the by-products of the process, more especially the ammonia, and all the gas for motive power purposes had of necessity to be made from either coke or a coal consisting for the most part of carbon, generally anthracite. In the Mond process, however, gas suitable for either fuel or motive power purposes is made from cheap bituminous slack, and at the same time the ammonia is recovered and can be sold at a profitable rate.

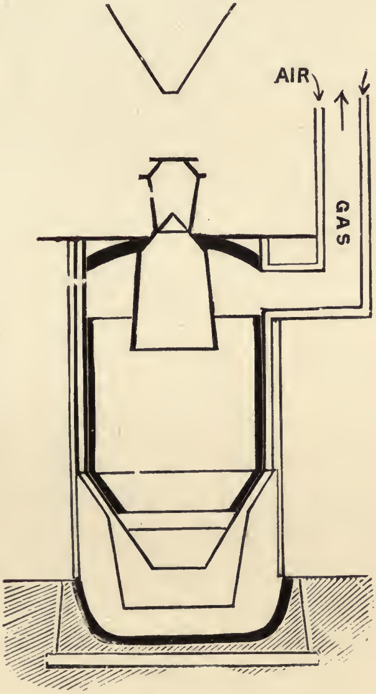


FIG. 36.—Mond Gas Producer.

The method of making Mond gas in use at the works of Messrs. Brunner, Mond & Co. is interesting and important as bearing on the more smokeless forms of boiler furnace, and may be gathered from the following brief description.

A diagrammatic representation of the arrangement of the producer is shown in Fig. 36. The slack is conveyed mechanically, by means of an elevator and creeper, to a measuring hopper, whence it is dropped by the attendant in definite quantities into the hopper of the producer. The producer itself is constructed of wrought iron, and is made with two walls, an inner and an outer wall. The top is domed and the bottom is made conical, with the apex of the truncated cone pointing downwards. A firebrick lining is supplied to the inner wall for about two-thirds of its height, and, reaching a little way down the conical bottom, the domed top is lined with firebrick also. The immediate top of the producer, through which the fuel is fed, is closed by a valve, which can be operated by the attendant when a new supply is required. From this valve the coal falls into a large cast-iron bell-shaped vessel, open at the lower end. The fuel remains in this vessel for some time, and, as it is surrounded by the hot gas coming off from the hotter fuel below, the fresh coal is distilled and the hydrocarbons driven off. The gases, as they come off, have to pass downwards into and through the hot zone, and in this way the tar is converted into fixed gas. A mixture of steam and air passes downwards between the walls of the producer, is heated in so doing, and passes through the fire bars at the bottom of the producer, upwards through the incandescent fuel, and a gas is produced by the passage of the steam and air through the incandescent fuel, consisting largely of H and CO. The ash collects at the bottom of the producer, and the top of the heap closes the opening.

When the combined gases pass off from the producer, they are at a high temperature, and are taken through a regenerator, consisting of a number of double vertical tubes. The hot gases pass along the inner tubes, and give up some of their heat to the air and steam which are traversing the outer tubes in the opposite direction on their way to the producer. The gases next pass through a "washer," where they are further cooled by intimate contact with water spray produced mechanically. They then pass upwards through the "acid tower," where they meet a downward stream of acid liquor, consisting of dilute sulphuric acid, which is passing downwards through a mass of chequered brickwork. Here the gas is deprived of its ammonia, and, passing through another cooling and cleaning tower, goes away to be used in the furnaces or gas engines, as the case may be. Fig. 37 shows the application of the gas to a water-tube boiler.

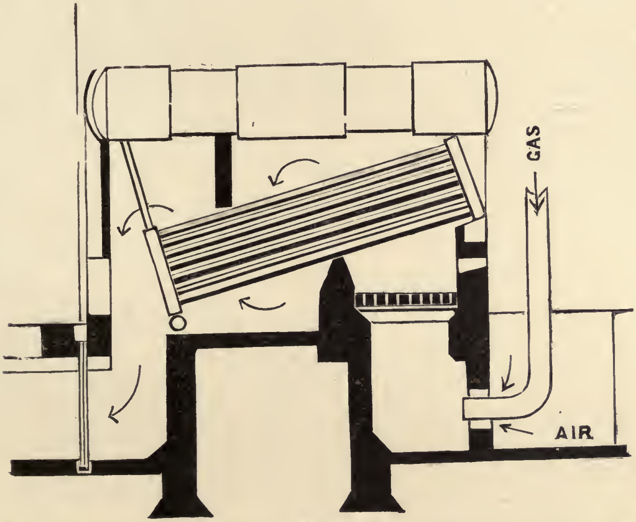


FIG. 37.—Application of Mond Gas to Babcock Boiler.

In a description of the plant by Mr. Humphrey in 1897 it is stated that the cost of the fuel at the works was 6s. 2d. per ton. The gas produced had a calorific value of 81 per cent.

of the calorific value of the original fuel, and, in the water-tube boiler used, gave an evaporation of seven pounds of water per pound of fuel. It is further stated that, comparing it with direct firing, about 1·15 ton of coal slack in the producers is equivalent to one ton when used on open grates in the usual way, but the advantages of the former method over the latter, as regards the smaller quantity of air required and the cost of labour and repairs, bring the two systems more on a level. Moreover in the Mond process the sale of the ammonia produced covers the cost of the fuel used, so that in this case the power is produced at the cost only of the labour and interest on the first cost of the plant. Of course it must be remembered that this is a large plant, and in case of smaller installations the advantage could not possibly be expected to be so great.

In the following table is given again the composition of some of the best known producer gases in order to compare these with Mond gas.

TABLE VII.—COMPOSITION OF VARIOUS PRODUCER GASES.

(From Humphrey on Mond Gas. *I. C. E.*, cxxix.)

Gas.	H	CH	CO	N	CO	Other Gases.	Combustible Gases.	Air required per cub. foot.
Mond producer from bituminous fuel . .	24·8	2·3	13·2	46·8	12·9	0·00	40·3	1·124
Siemens producer gas .	8·6	2·4	24·4	59·4	5·2	0·00	35·4	1·014
Dowson producer gas from anthracite . .	18·73	0·31	25·07	48·98	6·57	0·31	44·42	1·132
Solvay coke-oven gas .	56·9	22·6	8·7	5·8	3·0	3·0	91·2	4·10
Illuminating coal gas .	48·0	39·5	7·5	0·5	0·00	3·8	98·8	5·81
Pittsburgh natural gas .	22·0	67·0	0·6	3·0	0·6	6·0	95·6	8·06

The author of the paper from which the above figures were taken refers to the use of producer gas, in conjunction with gas engines, for the generation of power on a large scale, such as for driving the machinery of factories or the generation of power in central stations for electric distribution, and in order to make his points clear, he takes an imaginary case of a factory requiring 10,000 horse power continuously. The power is supposed in this case to be derived from gas engines provided with gas from a Mond producing plant placed in a position adjacent to the factory. The whole of the 10,000 horse power is to be used to drive dynamos which give out 7,000 horse power at their terminals, for transmission to various parts of the factory. Mr. Humphrey estimates the cost of the gas generating and recovery plant as about £20,000, and that of the engines and dynamos with the necessary buildings and accessories as £120,000. On this basis, and supposing the works to be run day and night, the cost per electrical horse-power-hour is estimated at 0·137d. Such a case as the above would be found in works where electrolytic processes were being carried out.

At the present time (March, 1901) a very interesting scheme is on foot to produce Mond gas in large quantities in a central station in Staffordshire, and to distribute this by means of pipes, for use at various points in the surrounding district for combustion in metallurgical furnaces and for driving gas engines. The scheme is particularly interesting in connection with the smoke question, because it marks the first real step taken in the direction indicated by the writer in a later part of this book, towards the centralisation of power and gaseous fuel production.

CHAPTER VI.

THE TESTING OF BOILERS, AND SMOKE OBSERVATIONS.

When a full test is to be carried out in order to discover the suitability or non-suitability of a smoke-preventing appliance, it is necessary not only to take smoke observations of the chimney top, but, at the same time, to rigidly test the boiler as regards its efficiency as a supplier of steam during the time the smoke appliance is in use. This is needful because it is no use fitting the boiler with some form of furnace which will burn the fuel smokelessly, at the cost of a very much reduced efficiency. A factory owner will not sacrifice the usefulness of his boilers in order to have a smokeless chimney, at any rate in the present state of the law on the subject, because in a great many cases it is found cheaper to pay the periodic fines that are imposed than to go to the trouble and expense of making radical alterations in the arrangements for consuming the fuel.

In a boiler test carried out under these conditions, the main point to be determined is the efficiency of the furnace as an economical fuel consumer, which is at the same time smokeless, rather than to test the boiler as a whole. The observations which are required are, apart from the smoke tests—

1. Measurement of the quantity of fuel used during the test.
2. Measurement of the quantity of water supplied during the test.

3. The pressure of the steam generated.
4. Temperature of the feed water and of flue gases.
5. Analysis of the fuel.
6. Calorimetric determinations of the heating power of the fuel.
7. Analysis of the flue gases.

Carrying out a Boiler Test.

When it has been decided that a test is to be made on a given boiler, all the apparatus used in the measurements is to be got ready and full instructions given to the several observers taking part in the trial. The duration of a boiler trial should be as long as possible, in order that any errors as to the amount of fuel on the grate bars at starting and stopping the trial may be reduced to a minimum. The trial should be continuous for ten or twelve hours. Where smoke observations are to be taken simultaneously with the other measurements, it will be found impossible to make the trial so long as this in winter, when the darkness will interfere with the smoke observations, and it is therefore well to choose a time when the days are longer.

Another important point to be observed is that the boiler should be in use under the conditions of the trial for some hours before the trial, in order that the flues may have arrived at their normal temperature when the test begins, so that no heat need be lost in warming up the flues.

When the trial is to commence, the fires, though fully working, should be as low as possible, the depth of the fuel on the bars being noted by seeing the number of bricks covered. Also the height of the water in the gauge is to be noted at the moment of starting. The test now begins, firing and feeding being carried out in the normal manner, the quantity of fuel and water as well as the temperature of the latter being noted as the trial proceeds. Periodic readings must also be taken every five or ten minutes of the height of the water in the gauges, the pressure of the steam by the steam gauge, the temperature of the flue gases as they leave the flues for the chimney, and as many analyses of the flue gases as it is possible to make in the time. As regards these latter the samples may either be collected and analysed individually as the trial proceeds, or continuous average samples may be collected and analysed at the end of the test.

The closing of a boiler trial is as important as the commencement. The main point to be aimed at is that all the conditions appertaining to the boiler shall be precisely the same at the end as at the beginning. To obtain this state of things requires a certain amount of skill and experience. The fireman, as the time approaches for stopping the trial, must be ready to manipulate his fires so that at the end there will be precisely as much fuel on the grate as there was at the commencement, or as nearly as possibly so. At the same time he must watch his feed, so as to get the gauge to the height it was at the commencement. If it is found impossible to get the water back to precisely the same point as it was originally, the actual height must be noted. These gauge observations are facilitated by having a graduated scale fixed behind each gauge, and a piece of string tied round the glass at the beginning of the trial at the height of the water will serve as a landmark to guide the fireman.

When the trial is over the fire should be drawn and a weighing made of (*a*) the unburnt fuel on the grate, (*b*) the clinker produced, and (*c*) the total amount of ash which has accumulated during the trial.

MEASURING INSTRUMENTS USED.

Fuel Measurement.—It is convenient to weigh out as much fuel as is likely to be required during the trial, and place this in sacks holding some definite quantity each, say, 100 pounds. These sacks should be tied up, labelled and possibly sealed as soon as they have been filled. They will then be ready for using when wanted, and it will only be necessary to empty each sack on the boiler house floor as the supply becomes exhausted. Probably part of a sack will be left on the floor at the completion of the trial, and this amount must be separately weighed and subtracted from that contained in all the bags which have been used to make up the total weight of fuel used during the trial.

If it is desired to measure the amount of moisture in the coal the best plan is to select samples as the trial proceeds and to weigh the total amount; place the sample on the top of the boiler to dry, and again weigh. The difference in weight divided by the weight of the dry fuel and multiplied by 100 will give the percentage of moisture in the fuel.

Also during the trial a small sample of fuel should be taken out of each sack. These samples are to be thoroughly mixed together at the end of the trial, and a small portion of this mixture reduced to powder and again thoroughly mixed will give a representative sample of the fuel from which to take a specimen for the purpose of analysis or calorimetry.

Measurement of the Feed Water.

The manner in which this is measured will depend on the arrangement for feeding the boiler. Generally the feed is pumped from a tank, and the water entering this tank can be measured by passing it through a calibrated tank or measuring vessel. The calibration must be made by actual weighing. The scale of weights can either take the form of a water-gauge glass up the side of the tank, or a pointer may be fixed to a float and move up a fixed graduated scale.

In some cases a piston water meter is used to measure the water either alone or as a check on the tank. If the former, the meter should not be trusted without an independent calibration previous to the trial.

A convenient way of measuring is to have two similar tanks calibrated in pound measurements, and connected to the feed pump through a three-way cock, so that the tanks can be emptied and filled alternately.

As the water passes out of the measuring tank its temperature must be measured by means of an ordinary mercury thermometer.

Measurement of the Pressure and Height of Water Gauge.

These two should be noted on a log form at regular intervals, say, every five minutes throughout the trial.

Temperature of the Flue Gases.

It is important to know this temperature, if it is desired to work out a complete heat account of the trial, in order to ascertain the amount of heat carried away by the flue gases. The temperature may be measured by means of some kind of pyrometer, either a water pyrometer or a direct reading pyrometer, which is allowed to remain in the flues during the whole trial; or a special high temperature mercury thermometer may be employed. When using an instrument of this kind it is well to have one provided with compressed nitrogen above the mercury, so as to obviate the boiling of the mercury. The flue temperature is generally somewhere in the neighbourhood of 500° or 600° F., and as mercury boils at a little over 600° it is important that this precaution be taken.

Analysis of the Fuel.

This is usually entrusted to a chemist, the engineer who is conducting the trial being careful that the sample submitted is a representative one.

Heating Value of the Fuel.

This can be found in one or more ways. Either a direct determination can be made by the engineer by means of a fuel calorimeter, or an estimate may be fairly correctly made from a chemical analysis of a sample of the fuel. Either or both these methods may be employed, care being taken that the sample is dry in both cases, and that a determination has been made of the percentage of moisture in the fuel.

The calorific value of a fuel may be defined as " the number of thermal units given out by the complete combustion of one pound of the fuel in question ". A thermal unit is the quantity of heat required to raise the temperature of one pound of pure water through 1° Fahr.

FUEL CALORIMETERS.

There are a good many kinds of calorimeters in use, but the principle is the same in all. A weighed quantity of the fuel whose calorific value it is desired to determine is burnt in such a way that all the heat generated is caught, as it were, in a form in which it can be correctly measured. The chief difficulty is found in this measurement of the heat. Perhaps the simplest form of calorimeter, though not the most accurate, is that of the Thomson type, shown in Fig. 38.

THOMSON'S CALORIMETER.

On reference to Fig. 38 it will be seen that the instrument is contained in a glass jar, which is itself placed inside an outer glass jar, there being an air space between the two, which acts as a non-conducting jacket to prevent the escape of heat. The fuel to be burnt is first powdered to the consistency of coarse gunpowder, all the fine dust being screened away as well as all the larger pieces. It is then thoroughly dried and the required quantity weighed out ready for testing. Two grammes is a usual quantity. This sample of the fuel is now put into a small copper or platinum crucible, which is placed in a diving bell, and the whole lowered into the water, as shown in the sketch. The top of the diving bell is of course closed, and at the bottom are openings through which the gases of combustion can escape. The position of the crucible is so arranged that the water in the bell does not nearly reach the fuel. Through the top of the bell is led a pipe conveying the oxygen gas used for the combustion. When the experiment is to be made the temperature of the water is taken with

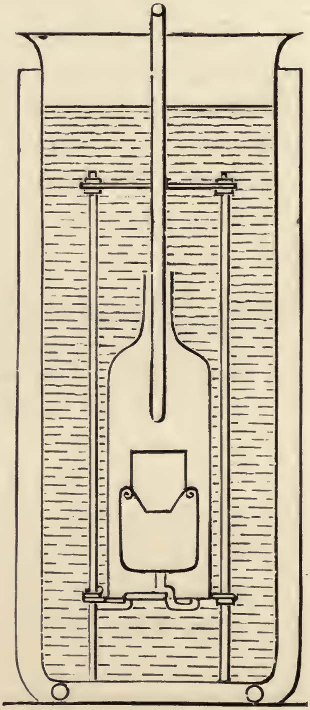


Fig. 38.—Thomson's Fuel Calorimeter.

a very sensitive thermometer, great care being observed in stirring the water thoroughly, so as to get a mean temperature. The diving bell is then lowered into the water with a small piece of fuse placed in the fuel and ignited. As soon as the bell has been lowered to the bottom of the jar, oxygen is allowed to enter by way of the pipe and play on the top of the fuel. Rapid combustion now takes place, the hot gases leaving the bottom of the jar and rising through the water, giving up most of their heat, and so raising the temperature of the water. Care must be taken with the supply of oxygen, just enough being admitted to keep up a steady, uniform combustion—too much will probably blow away some of the coal, and too little will probably result in smoke. It is convenient to have the bell and the containing vessels of glass so that the combustion of the coal may be watched and the oxygen the better regulated. In fact, to watch the combustion of a sample of coal in oxygen is an excellent lesson in smoke production, and the two periods, that of gasification and that of the combustion of the remaining carbon, are very well marked. At the end of the test, when all the coal is burnt and the water has been allowed to penetrate the bell and take up the heat from those gases which have not already escaped, and the water been thoroughly well stirred, the temperature of the water is again taken. The difference between the final and initial temperatures, or the rise in temperature, multiplied by the weight of water in pounds, will give the number of heat units given to the water, and this number divided by the weight of fuel consumed, also in pounds, will give the number of heat units yielded per pound of the fuel, or its calorific value, which is what is required. This quantity as at first found requires a correction in order to allow for radiation, and the heat absorbed by the material of the instrument. This allowance is generally made by finding a constant for the instrument by burning some carbon of known calorific value. The radiation can be reduced by arranging that the temperature of the water at the beginning of the experiment is as much below the temperature of the atmosphere, as it is above this temperature at the end, so that there is a radiation first inwards and afterwards from the instrument outwards.

The disadvantage of this calorimeter is that it is not possible to be sure that the whole of the heat generated has been given up to the water, because the gases pass through the water and escape into the air above. The speed of exit is not always the same, the temperature of the gases must vary considerably with different fuels, and, as gas is a very bad conductor of heat, it is unreasonable to suppose that during the very short time of passage through the water each bubble of gas will be able to part with all its heat. This would be effected more thoroughly if the bubbles of gas could be broken up by mechanical means into very small particles.

BOMB CALORIMETERS OF BERTHELOT AND MAHLER.

In this form of calorimeter the whole of the heat is extracted from the hot gases. The radical difference between this type and the Thomson calorimeter is that the combustion is effected very rapidly in a vessel which is sealed during the combustion, and the water is allowed to flow in at the end of the experiment, no gases being allowed to escape.

A calorimeter of this kind is costly, chiefly on account of the bomb itself. This must be made of some material such as platinum, which does not easily oxidise. In the Berthelot instrument, the first of this type, the crucible is of platinum, and the bomb is of steel and lined with platinum. In M. Mahler's form of this instrument a considerable saving in cost is effected by making the bomb of steel as before and lining it with enamel instead of platinum. The outside of the bomb is nickelled to prevent rust.

In Mr. Bryan Donkin's calorimeter, which is of the same type, the bomb is gilt inside, and thus rendered non-corrosive. In size it is designed to burn one gramme of fuel, coal or oil.

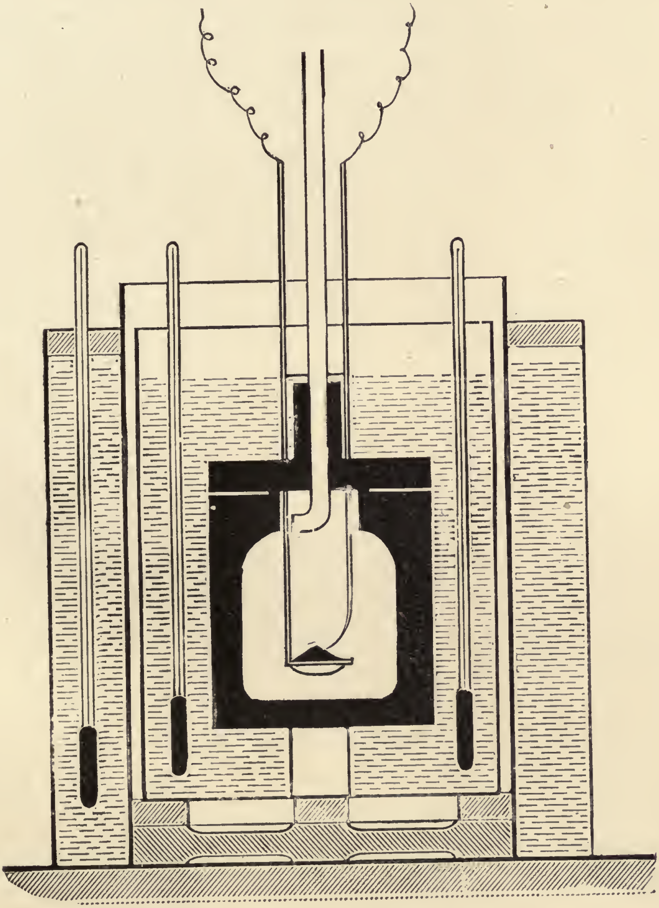


FIG. 39.—Donkin's Fuel Calorimeter.

A general view of this is shown in Fig. 39. The instrument is enclosed in an outer vessel, which is covered with a non-conducting external layer. This outer vessel is filled with water, whose temperature can be noted by means of a thermometer. Inside this first vessel is another, and, again, inside this is the calorimeter jar itself, an air space being left between the inner jar and the second vessel. By these means the radiation is reduced to a minimum, and the actual quantity of heat passing from the calorimeter jar in an outward direction can be measured. The bomb is supported in the centre of the interior vessel, which is filled with water, and a mechanical stirrer, which is not shown, is used for the purpose of reducing the water to a uniform temperature. Two sensitive thermometers are used for getting the rise of temperature. When starting an experiment the temperature of the water in the calorimeter jar is carefully taken, next the fuel is placed in the bomb, which is then sealed up, and the bomb filled with oxygen at some twenty atmospheres' pressure, the bomb placed in the water and the fuel fired electrically. Rapid combustion takes place, the water is stirred for ten minutes, when the temperature is again taken, and the bomb washed out with water. From the two temperatures of the water, the weight of the water, and the weight of the fuel, the calorific value may now be determined, due allowance being made for radiation and for the heat taken up by the parts of the instrument.

Calorific Value from Analysis of the Fuel.

When an accurate analysis of the fuel is obtained a very near approximation to the true calorific value can be obtained by assuming each constituent to give up its own quantity of heat and to add together these quantities. In doing this, only the carbon and hydrogen are taken account of, the sulphur being neglected for the reason that its quantity is relatively small and its calorific value low.

The calorific values vary somewhat according to different authorities, but those given by Dulong are—

Hydrogen	62,100	thermal units.
Carbon	14,650	,,
Sulphur	4,032	,,

Other authorities give these as 62,000, 14,500 and 4,000 respectively, and these are the values often used for rough calculations.

Dulong's formula is—

$$V = 14{,}650\ C + 62{,}100\left(H - \frac{O}{8}\right)\ .\ .\ .\ (a),$$

allowance being made for the oxygen in the fuel, on the assumption that its equivalent of hydrogen is to be neglected as far as heat-giving qualities are concerned. There is a divergence of opinion on this point, and it is found that when the whole of the hydrogen is taken into account a result is obtained nearer the experimental determination. The formula then becomes—

$$V = 14{,}650\ C + 62{,}100\ H\ .\ .\ .\ (b),$$

or, using the second set of values, it is—

$$V = 14{,}500\ C + 62{,}000\ H\ .\ .\ .\ (c).$$

Mahler devised the following empirical formula as the result of a long series of experimental investigations—

$$V = 14{,}650\ C + 62{,}100\ H - 5{,}400\ (O + N)\ .\ .\ .\ (d).$$

In order to compare these formulæ the following values have been worked out for the same sample of coal. The analysis was as follows:—

ANALYSIS OF SAMPLE OF COAL.

Carbon	87	per cent.
Hydrogen	5	,,
Oxygen	3	,,
Nitrogen	1	,,
Sulphur	0·8	,,

Taking Dulong's formula—

$$\begin{aligned} 14{,}650 \times 0{\cdot}87 &= 12{,}750 \\ 62{,}100 \times \left(0{\cdot}05 - \frac{0{\cdot}05}{8}\right) &= \underline{\ \ 2{,}950} \\ & \ \ \ 15{,}700\ .\ .\ .\ (a). \end{aligned}$$

The values as given by the other formulæ are—

15,855 . . . (*b*).
15,700 . . . (*c*).
15,639 . . . (*d*).

It will be seen that here (*a*) and (*c*) agree perfectly and (*d*) is very nearly in agreement, and any one of these three may be expected to give results differing only by a very small fraction of the whole amount.

It must be explained that the letters H, C, N and O denote the weight of hydrogen, carbon, nitrogen and oxygen respectively in one pound of the fuel; and the result obtained, V, is the number of thermal units given out by the complete combustion of one pound of the fuel.

Analysis of the Flue Gases.

This is a most important measurement in all boiler trials and should be made with great care. It can be divided into two stages, namely, the collection of the samples and the analysis of the samples so collected.

Collection of the sample.—First, a suitable place must be selected from which to take the gas. This should be at a point in the flues where combustion is complete, generally just where the gases leave the last flue which traverses the boiler. The sample should be drawn through an iron or glass pipe inserted well into the centre of the flue. Before a boiler trial is allowed to commence, great care should be taken that no air reaches the inside of the flues beyond what passes through the boiler. The brickwork surrounding a boiler is often leaky and much air may be passing into the flues. When this is the case a quite erroneous idea will be given of the composition of the flue gases, due to the presence of a large amount of excess air which does not really belong to the gases which have traversed the flues. Leakages must be tested for by a candle flame, or smoke from burning brown paper, and all leakages so found luted up with clay. This is a precaution often neglected. The writer remembers a case where the analysis of the gases registered only 2½ per cent. of CO_2 when the boiler was working under very fair conditions. It was found on subsequent examination that there were a large number of crevices in the brickwork, and air was leaking inwards in large quantities. Of course in this case the percentage obtained was absolutely incorrect so far as the actual flue gas was concerned.

The collection may either be made in the analysing apparatus itself or it may be collected in bottles and analysed separately.

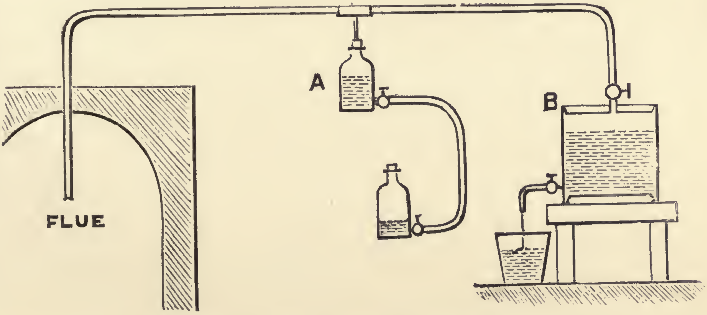


Fig. 40.—Gas Collecting Arrangement.

If the latter, the best arrangement is that shown in the accompanying Fig. 40. Here a pipe is shown leading from the interior of the flue. This pipe is connected by a rubber tube with a T piece, the vertical portion of the T being connected to the collecting bottle A. The remaining horizontal arm of the T is connected with an aspirator, B, which is simply an airtight vessel, filled with water at the beginning of the test. The water is allowed to flow out through a tap at the bottom and its place is taken by gases from the flues. If an average sample is desired, the water is allowed to trickle out of the tap very slowly, thus obtaining a continuous flow of the gases along the horizontal pipe; and an average sample may be taken from this in the collecting bottle by allowing the fluid, with which the bottle has been filled, to run slowly out through the tap provided at the bottom. The best fluid for this purpose is mercury, which can be allowed to run into another bottle placed below. If water is used it must contain a very strong solution of common salt, in order to prevent any absorption of the CO_2 in the gases. Of course there is no necessity to take any precaution of this kind if mercury is used. When a bottle is full of the gases it must be disconnected and carefully corked up. The cork should be thoroughly sealed to prevent any air getting into the gases. In collecting the gas in this way the bottle should be placed in as cool a place as possible, as the gases come from the flues hot, and if they are still hot when the bottle is corked they will contract in volume and tend to suck in air through any crevices there may be. Leakage of air is also to be avoided in making the pipe connections, both when collecting and when using the apparatus.

Analysis of the sample.—There are several forms of apparatus in use for this purpose. The principle is the same in all, namely, the absorption of the different constituents in order, measurement of the total volume before and after each stage, and noting the diminution caused by the absorption. It will be sufficient here to briefly describe one of the best known pieces of apparatus. This is what is called the Orsat apparatus for volumetric gas analysis. A general view is shown in Fig. 41. In using this apparatus the gas is collected in the graduated tube, A. This tube is connected at its lower end by a rubber pipe with a water bottle. When this is placed on the top of the box, which contains the whole apparatus, the water flows down and the measuring tube can be filled up to the top graduation by holding the bottle in the hand, and raising or lowering it until the surface of the water is at the proper level.

The measuring tube is divided into 100 cubic centimetres. From the top of this is a horizontal glass pipe, connected, by means of taps, with three absorbing vessels. When a sample is to be collected the pipe is connected to the T piece of the aspirator, the taps to the absorption vessels being closed. The gas is now drawn into the vessel by the gradual lowering of the level bottle, until the level of the water in the bottle and in the tube are at the height of the zero of the scale. The vessel now contains 100 cubic centimetres of the gases. The admission cock is closed. The first vessel is full of a strong solution of caustic potash, and the whole of the sample

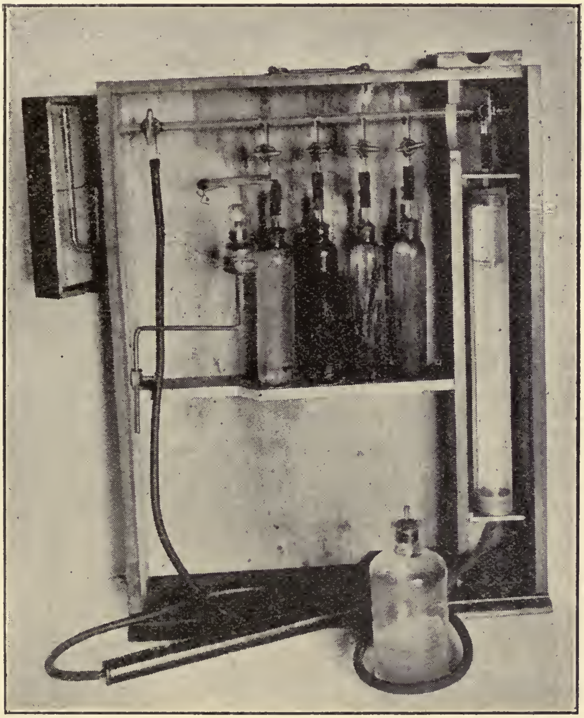


Fig. 41.—Orsat Gas Analysis Apparatus.

is next carried over into this vessel by raising the level bottle until the water again reaches to the top of the scale, all the other cocks being closed. A few short pieces of glass rod or tube are usually placed in the vessel to increase the absorbing surface. In about five or ten minutes all the CO_2 in the gas will have been absorbed, and the remaining gas may be returned to the measuring tube by lowering the level bottle until the caustic potash again fills the pipette. The water in the level bottle must now be placed at the same level as the water inside the tube, so as to have the gas at atmospheric pressure, because the top of the level bottle is open to the air. The reading is then taken, and the height of the water gives the diminution of volume, and consequently the percentage of CO_2 present in the gases. The second pipette is filled with sticks of phosphorus to absorb the oxygen, and the same process is gone through for this as in the former case. When the gas is admitted to the phosphorus pipette it will be noticed that it soon becomes filled with a dense, white smoke, consisting of fumes of phosphorus pentoxide, and time must be allowed to elapse until these fumes have quite cleared away before the gas is returned to the measuring vessel. The diminution of volume is now that due to the CO_2 and the O together, and the percentage of CO_2 must be subtracted from this to get the percentage of O. The third pipette contains a strong solution of cuprous chloride in hydrochloric acid. This absorbs the CO if any is present. Instead of phosphorus for the oxygen absorbent a solution of pyrogallic acid in caustic potash is sometimes used. When starting a collection of gas, the aspirator must be allowed to run for some minutes, to get all the air out of the pipes before a sample is taken, and just before collecting in the measuring vessel, the top cross pipe must be exhausted of air by means of a rubber exhauster, which is generally provided with the apparatus. The Orsat apparatus, which is made in Germany, may be bought complete (without the chemicals) for about three pounds. It will be found that the correct use of this appliance requires a considerable amount of careful practice. The writer advises any one beginning to use it to go through the different operations very slowly and deliberately, as any attempt to go quickly at first will be sure to result in failure, owing to one of the many little operations being forgotten. For practice it is a good plan to go through the operations a few times with air in the measuring vessel.

The other types of apparatus for analysing flue gases are precisely the same in principle, but are generally more cumbersome to use and not so compact as the Orsat.

RESULTS OF A TRIAL.

The most important results to be obtained from a boiler trial which is being worked in conjunction with a smoke test are the following:—

1. The number of pounds of water evaporated at and from 212 ° per pound of the fuel.
2. The thermal efficiency of the boiler and furnace.
3. Pounds of fuel burnt per square foot of grate surface per hour.
4. Temperature of the flue gases.
5. Analysis of the flue gases.
6. Pounds of air per pound of coal.

Water, at and from, 212° *per pound of fuel.*—It is easy to obtain the total quantity of water evaporated, and, dividing by the weight of fuel consumed in the same time, the weight of water evaporated per pound of fuel will be given. The weight of fuel should be for dry fuel, that is, the fuel as actually measured minus the percentage of moisture as found by the separate determination. But the heat required to evaporate one pound of water depends upon the pressure, and consequently the amount of heat taken up in turning the water into steam. The higher the pressure the more heat is taken up in bringing about vaporisation, or, in other words, the latent heat of the steam is greater. So that it is not fair in comparing results to simply take the water evaporated irrespective of its pressure.

What must be done is to take the water evaporated per pound of dry fuel, as obtained, and to divide this by the ratio of the latent heat of steam at atmospheric pressure (212°) to the latent heat of steam at the pressure in question as found from the pressure observations and from a table of the properties of saturated steam.

In order to illustrate the working out of the main results of a boiler trial it will be convenient to take an actual example, as follows:—

Boiler trial carried out on a Lancashire boiler, 28 *feet by* 6 *feet.*—Data obtained from observations:—

Duration of trial	10 hours
Calorific value of dry fuel	14,200 B.T.U.
Percentage of moisture in fuel . . .	2 per cent.
Area of grate	19 sq. ft.
Total weight of coal burnt	3,000 lb.

Analysis of flue gases:—

CO_2	12·2 per cent.
O	6·7 ,,
CO	0·02 ,,
Temperature of feed	60°
Total weight of water evaporated . .	25,500 lb.
Temperature of furnace gases at end of boiler	550° F.
Steam pressure in pounds per sq. in. by gauge	72

From these figures obtained during the trial it is desired to find—

The pounds of dry coal burnt per square foot of grate area.
The pounds of air per pound of coal.
The evaporation at and from 212° per pound of dry coal.
The boiler efficiency.

Taking these in the order named :—

Pounds of dry coal burnt per square foot of grate.—First get the weight of dry coal. This is done by subtracting the moisture from the wet coal, or total pounds of dry coal burnt = 3,000 − 60 = 2,940 lb. Then pounds of dry coal burnt per square foot of grate per hour—

$$\frac{2{,}940}{19 \times 10} = 15{\cdot}5 \text{ lb.}$$

Pounds of air per pound of coal is obtained from the percentage of CO_2 in the flue gases by means of the formula already given ; thus pounds of air per pound of coal—

$$a = 11{\cdot}5\,\frac{18{\cdot}4}{CO_2} = 17{\cdot}8 \text{ lb.}$$

Evaporation at and from 212°.—The absolute pressure of the steam is 72 + 15 = 87 lb. per square inch. The temperature of the steam corresponding to this is, as found from the steam tables, 318° F., and its total heat, that is the number of thermal units required to raise one pound from 32° to boiling point and totally evaporate it, is found to be 1,179 B.T.U.

But the feed water is already at 60°, so that from the total heat must be subtracted the difference between 60 and 32, or 28. This gives 1,151, which represents the heat given by the fuel to each pound of the water evaporated in the present case. Now, the pounds of water evaporated per pound of dry coal are—

$$\frac{25{,}500}{2{,}940} = 8{\cdot}68 \text{ lb.}$$

But, in order to reduce this to standard conditions, the total amount of heat used per pound of the coal must be found for the 8·68 pounds of water. This is—

$$8{\cdot}68 \times 1151 = 10{,}000 \text{ B.T.U.,}$$

and, if this is divided by 966, the amount of heat required to evaporate one pound of water at the temperature corresponding to atmospheric pressure, namely, 212°, the water being at this pressure when the heat is first applied, the required result is obtained. Or, pounds of water per pound of coal at and from 212°—

$$\frac{10{,}000}{966} = 10{\cdot}34 \text{ lb.}$$

Boiler Efficiency.—For one pound of dry coal burnt there are 8·68 pounds of water evaporated, each of which requires for its evaporation 1,151 B.T.U. Also, each pound of dry fuel coal gives out during its combustion 14,200 B.T.U. So the heat used in each pound of water, divided by the heat given to each pound of water and multiplied by 100, will give the efficiency of the boiler, or thermal efficiency of boiler—

$$\frac{8{\cdot}68 \times 1{,}151 \times 100}{14{,}200} = \frac{10{,}000}{14{,}200} \times 100 = 70{\cdot}5 \text{ per cent.}$$

In order to bring home to the mind of the reader the amount of heat carried away in the flue gases, the following calculation for this particular case is worked out:—

Weight of air per pound of coal = 17·8 lb., consequently for one pound of coal there will be 1 + 17·8 = 18·8 lb. of flue gases.

Assuming the temperature of the incoming air to be 70° and the temperature of the flue gases 550°, each pound of the flue gases is raised in temperature 550 − 70 = 480°.

From the following table the specific heat or capacity for heat is 0·234.

Therefore, the flue gases from each pound of coal carry away—

$$480 \times 18{\cdot}8 \times 0{\cdot}234 = 2{,}110 \text{ B.T.U.,}$$

or

$$\frac{2{,}110}{14{,}200} \times 100 = 14{\cdot}9 \text{ per cent. of the heat given out.}$$

The following table may be found useful :—

TABLE VIII.—SPECIFIC HEATS OF FLUE GASES WITH VARIOUS PERCENTAGES OF CO_2.

Percentage of CO_2 in flue gases.		Specific heat of gases.
By weight.	By volume.	
31·4	20·0	0·234
23·5	15·0	0·234
15·7	10·0	0·235
7·8	5·0	0·235
3·9	2·5	0·236

The specific heats given here are for constant pressure. This is what is required in boiler work, as the gases are allowed free expansion and contraction, and the pressure does not vary greatly.

SMOKE OBSERVATIONS.

There is no set of standard rules to enable experimenters to compare the amount of smoke given out by different furnaces under varying conditions. Each authority has its own system of comparison, and it is not an easy thing to bring observations made under these different rules in line, so as to make a general comparison. For instance, a given furnace may be tested for smoke in Paris under the system adopted by the Paris Smoke Commission, and another furnace may be tested in Manchester, and the results given in terms of the system made use of in the Lancashire trials of 1895. Under these circumstances there is no possibility of a reasonable comparison being made.

No doubt, in the course of a few years, when these tests become more general, the system will gradually crystallise into one of greater uniformity. It is possible, however, to describe the best of the methods which have been used.

The first question which arises is, how is the quality of smoke issuing from a chimney to be defined? One of two general methods may be employed, namely, by *weighing* or by *the appearance of the smoke.* In the hot flue gases issuing from the chimney there is a certain quantity of finely divided carbon in suspension. A sample of these gases may be collected, the carbon separated and weighed, and the result expressed as a certain weight of carbon for a certain volume or weight of the gas. This is one method, and may be regarded as scientifically accurate, but it is not by any means easy to perform, much difficulty being experienced in separating the whole of the carbon from the gas for the purpose of weighing.

In the other, and much more simple method, the depth of colour of the flue gas as it issues from the chimney top is made the basis of comparison. This, besides being simpler and easier to perform, may be regarded on the whole as the most satisfactory way of gauging smoke. Attempts have also been made to form an idea of the amount of smoke in the gases by inserting cards coated with some sticky substance into the boiler flue for certain definite periods of time, and comparing the density of the tint produced by the adhesion of the carbon. This method will be found useful for collecting evidence as to the amount of smoke deposited in a given district, when making outdoor observations.

Time-density Scales.

Although it is not possible to make the method absolute for quantitative purposes, the use of some kind of smoke scale with which to compare the appearance of the chimney top is the most satisfactory method of smoke observation. The gases issuing from the top of a chimney are either invisible or they contain smoke of a greater or less density, according to what is happening in the furnace. This density varies from time to time, being greatest just after firing and diminishing as the first stage of combustion becomes complete. If, then, an observer be stationed in full view of the chimney, and notes the density of the smoke at regular intervals of time, say, every half minute, it will be possible to construct a diagram showing graphically the density of the smoke at every moment. This is practically what is done in the case of most smoke observations, the chief differences in the systems adopted being in the ways in which the density of the smoke is estimated. In most cases a number of definite densities are used, and the smoke is specified to be one or other of these at any moment. The following are some of the scales that have been used :—

Manchester Smoke Abatement Committee.—A scale of ten shades was used, and the observer watched the chimney and noted the shade of the smoke and the time during which it was being emitted. He had the scale of shades before him and compared the chimney smoke with it. There were in this case too many shades used, and the observations should have been taken at regular intervals.

English Smoke Abatement Committee (1895).—In this case only four shades were used, namely, "dense," "medium," "faint" and "no smoke". The observer watched the chimney and, at intervals of one minute, he recorded the density at that moment, denoting it by the figures 3, 2, 1, and corresponding to the above densities. The average of these figures was taken as giving the minutes of dense smoke in ten hours. This gives a fairly definite and simple basis of comparison. In this Commission photographs were also taken of the appearance of the chimney. These were useful for reference, but have the disadvantage of varying in density according to the manner of developing and printing.

Paris Smoke Tests (1897).—In these a method similar to the above was adopted, but the complete scale contained five in place of four densities. They were "very thick smoke," "black smoke," "medium smoke," "slight smoke" and "no smoke". The densities were plotted directly by the observer on a rotating drum, at half-minute intervals, the result being a continuous curve, and the area enclosed by this curve for a given interval of time was taken as a measure of the density of the smoke, and a value was worked out from a formula and called the "representative smoke number".

Swiss Smoke Scale.—A scale used in Switzerland has six densities, each having a value assigned to it, so that the density at any moment can be reduced to the equivalent black smoke. These are "thick black smoke" (3), "dense smoke" (2), "brownish grey smoke" (1), "light brown smoke" ($\frac{1}{2}$), "white transparent vapour" ($\frac{1}{4}$), and "no visible gases" (0).

Prussian Smoke Commission.—The method of taking the smoke observations in this was far too elaborate and expensive to be of much practical use for everyday work. A photometric arrangement was used, by which a ray of light was passed through the smoke in the flue, and the appearance of this was compared with a standard tint obtained from the light of a candle.

Ringelmann's Smoke Scale.—In this system a series of tints are obtained by drawing black lines on white paper, the lines having definite thicknesses and placed at definite distances apart. A scale thus prepared is placed at a distance of about fifty feet from the observer, and he sees which tint on the scale corresponds with the smoke coming from the chimney, and makes his record accordingly. The dimensions used in the figures are as follows :—

Ringelmann's Smoke Scale.

No. 5. Very black smoke.	All black.
,, 4. Black smoke.	Black lines 5·5 mm. thick and 4·5 mm. apart.
,, 3. Very dark grey smoke.	Black lines 3·7 mm. thick and 6·3 mm. apart.
,, 2. Darker grey smoke.	Black lines 2·3 mm. thick and 7·7 mm. apart.
,, 1. Light grey smoke.	Black lines 1 mm. thick and 9 mm. apart.
,, 0. No smoke.	All white.

Reproductions of Nos. 1, 2, 3 and 4 of this scale are given in Fig. 42.

The above comprise the principal scales which have been used. Which is the best method it is hard to say, but probably the last is as good as any, both because there are not too many shades attempted, and more especially because the tint is a definite one and leaves less to the judgment of the observer than in the cases of the other scales. It would be an excellent thing if all smoke observers could agree to adopt one uniform system in order that results by different observers and in different parts of the world might be compared on a definite basis. By combining Ringelmann's scale with the use of the rotating drum used on the Paris trials a very suitable arrangement could be effected.

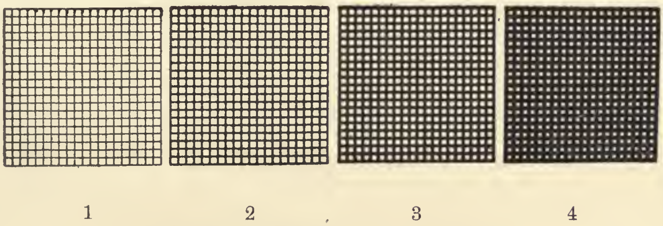


Fig. 42.—Ringelmann's Smoke Scale.

Mr. Bryan Donkin quotes a result obtained by Professor Lewicki. An estimation of the amount of soot in a given

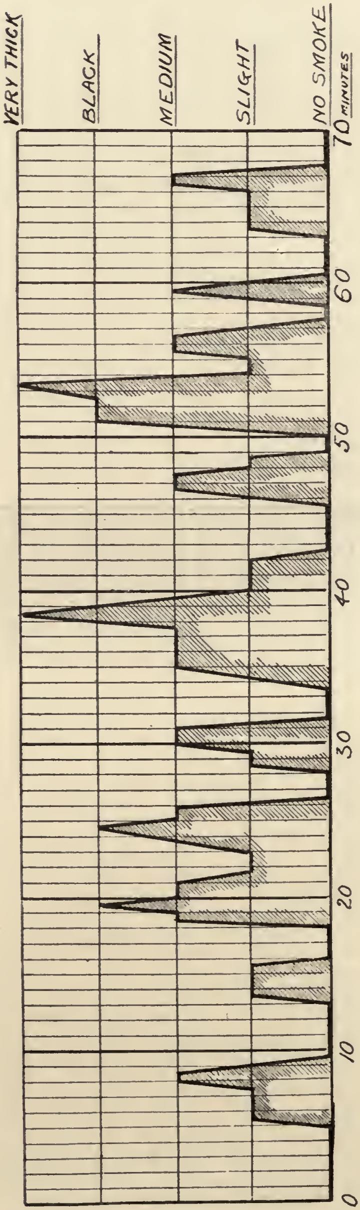


FIG. 43.—Smoke Diagram taken by the Author.

OF
CALIFORNIA

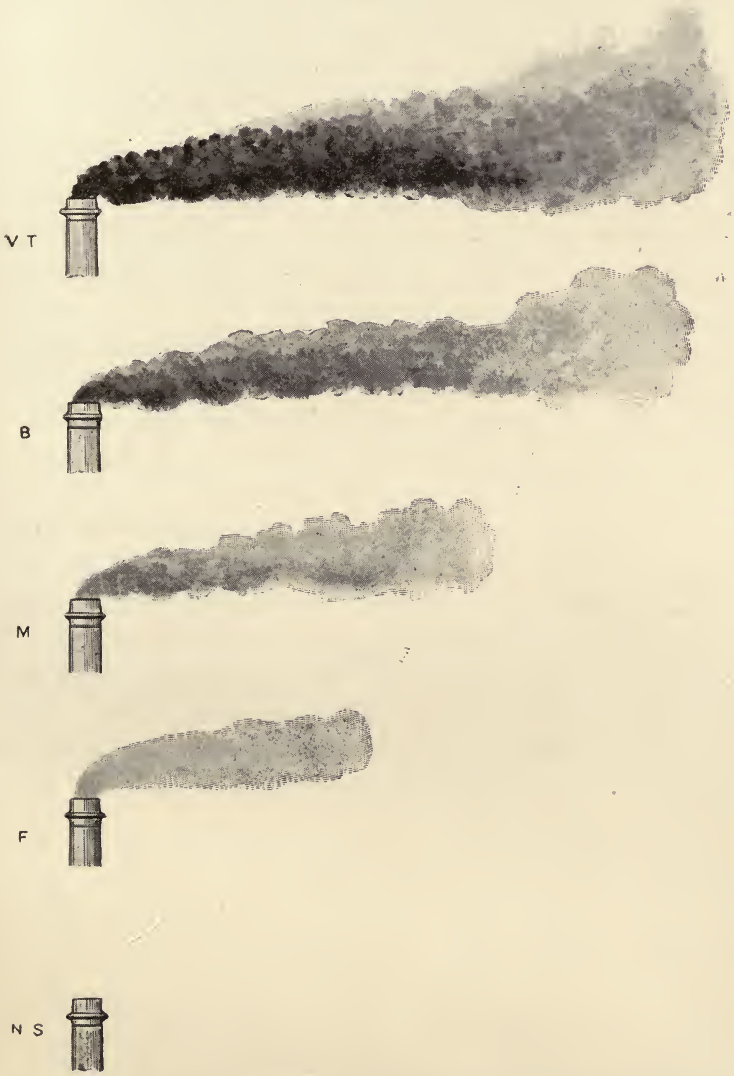


FIG. 44.—Appearance of Chimney Tops according to the Paris Smoke Scale.

V. T.—Very thick.
M. —Medium.
B.—Black.
F.—Faint.
N.S.—No smoke.

quantity of the flue gases was made from the samples collected for analysis. In this case there was only an appearance of a little light smoke, and the quantity of soot in one cubic metre of the gases was 0·33 gramme, the quantity of soot for one kilogramme of the fuel was 6·24 grammes, and the ratio of volume of soot to volume of gases at the temperature of the flues was found to be 0·0000147.

From these figures it will be seen that in this case the weight of unconsumed combustible is only 0·624 per cent.—about $\frac{2}{3}$ of 1 per cent.

In the accompanying Fig. 43 the author has plotted a smoke diagram taken by him from a typical cotton mill chimney, the scale used being the Paris Scale. The observations were taken every half minute, one vertical interval being equivalent to a degree of density as given by the scale.

It is well, when taking a set of smoke observations of a chimney, to make notes, where they are available, of the times of firing, cleaning, etc., so as to give some indication as to the causes of the smoke fluctuations. If the test is an important one, two observers should be at work simultaneously, so as to check one another.

The appearance of the chimney top corresponding to the "shades" of the Paris scale is shown in Fig. 44.

CHAPTER VII.

SOME STANDARD SMOKE TESTS.

From time to time the question of smoke abatement has appeared before the public in a more or less acute form. Many of our leading men, both scientific and lay, have taken up the subject with the greatest enthusiasm, but the strides made in the direction of a permanent improvement have not been at all in proportion to the trouble taken and the expense involved. It is to be regretted that this is so. That things will gradually improve may be regarded as certain, but probably this improvement will not be altogether in the manner anticipated by the pioneers in smoke abatement.

However, good work has been done, and much most valuable information has been collected and reduced to a permanent form in the reports of the various commissions. This intermittent crusade against smoke has taken various forms. One or two exhibitions have been held, elaborate and lengthy trials have been carried out on boilers fitted with various forms of furnaces and " smoke prevention appliances," and stoking competitions have been held, in which prizes have been given for smokeless and economical firing. Some of these will now be examined.

English Smoke Commission (1881).

This commission held an exhibition in 1881, at South Kensington, of various smoke-preventing appliances, and also undertook the testing of a number of furnaces and grates as regards their smoke-preventing possibilities. Among the appliances tested were the grates of Chubb, Duncan and Martin, and the mechanical stokers made by Sinclair and Proctor.

Second English Commission (Report published 1895).

The committee appointed several years previously to 1895 carried out some of the most valuable work that has ever been done in this direction. Not only did they make a long series of tests on appliances of all kinds, but they collected together and embodied in their report many tests made by authorities other than themselves.

In the report published by the Committee for Testing Smoke-Preventing Appliances is contained some of the most useful and important information on the subject which has yet been got together, and it is therefore proposed to give here a brief summary of the course adopted by this committee and the results obtained in the tests carried out by them.

When this committee was formed in 1889 a good deal of information bearing on the subject had already been collated by the National Smoke Abatement Institution, London, and by the Manchester and Salford Noxious Vapours Association. A smoke abatement exhibition was held in London in 1881 and another in Manchester in 1882. It was held by the committee that the work already done in connection with these exhibitions was very good, but that it embraced too wide a range, and that it was desirable to carry on the work thus already begun by concentrating their attention on the production of smoke by boiler furnaces, and to carry out a number of tests on the various appliances which were then on the market in full detail. The avowed objects of the committee in beginning their work were, in their own words :—

"1. Collation of the results of past experience.

"2. Examinations or tests to be conducted by experts appointed by the committee, at places where the appliances for, or methods of, consuming coal smokelessly are already at work, with the object of ascertaining whether, under ordinary working conditions, these methods or appliances do produce, or are accompanied by (*a*) practical freedom from smoke, (*b*) reasonable amount of duty, (*c*) economy of fuel, (*d*) moderate cost in wear and tear and simplicity of construction, (*e*) moderate cost of application.

"3. Examinations or tests to be conducted on premises temporarily occupied, and furnished with boilers, chimneys and apparatus of such appliances or methods as cannot be adequately tested where they are in use, and which are of sufficiently promising and distinct a character.

"4. Issue of a report embodying the results of the committee's operations."

How well and thoroughly this work was carried out will be judged from the following summary of the results.

Any firm who wished to have the appliance made by them tested, was required to fill up the following form :—

COMMITTEE FOR TESTING SMOKE-PREVENTING APPLIANCES.

FORM OF APPLICATION FOR TEST.

TO THE COMMITTEE.

GENTLEMEN,

..................request that the appliance (or method) for the prevention of smoke in use at.. may be tested by your engineer, and in consideration of such test being made.......................hereby accept and agree to the conditions annexed hereto.

Yours, etc.,

Name..

Address...

Date..

Description of appliance or method for smoke prevention.

....

....

Full list of addresses of firms using the appliance or method, indicating those who are willing to allow tests to be made.

....

....

....

....

NOTE.—If the spaces allowed for description of appliance and list of places where it is in use are insufficient, full particulars should be entered on separate sheets of same size as this and attached hereto.

CONDITIONS.

1. That the acceptance of these conditions be regarded as a binding agreement.

2. As soon as the results of a test are ascertained the committee may, if they think fit, publish the same. Pending the issue of such statement none of the details shall be made public.

3. The payment of a subscription of £25 entitles the subscriber to one test, the results of which shall be given to him in a form, copies of which may be had by intending applicants from the secretary, Mr. Fred Scott, 44 John Dalton Street, Manchester.

4. The committee reserve the right to decline to make any test applied for.

5. In case the committee desire to repeat the whole or any part of a test at any time the subscribers shall give every facility for doing so, but such repetition will not render the subscriber liable to any further payment.

6. The services rendered by the engineers, firemen or labourers at the works shall involve no charge to the committee.

7. A subscriber being a patentee or maker of appliances shall, if the committee desire it, give a *complete* list of places where the appliance or method for which he requires a test is in use.

When the work was to be begun Mr. E. W. Parnell was appointed engineer to carry out the tests, but very soon after commencing his work Mr. Parnell died, and Professor Kennedy was appointed to carry on the work. The funds of the association did not, however, permit of this arrangement being carried through, and it was decided to continue the work under the direction of the honorary secretary (Mr. Herbert Fletcher, of Bolton); and the chairman (Mr. A. E. Fletcher), assisted by his son, Mr. Herbert Fletcher, took the engineering side, and Mr. A. E. Fletcher the chemical portion of the tests. In all thirty-six full tests were carried out by the committee in Lancashire, and in the results which are tabulated thirty-three more were added, these being collected from tests made in London and Glasgow, and, in addition to these, several more are given, as published by the Sheffield Smoke Abatement Association.

METHODS USED IN CARRYING OUT THE TESTS.

Samples of the coal used were taken at intervals throughout each test and a general average sample obtained from these at the end of the test. From each sample thus obtained calorimetric determinations were made by means of a Thomson calorimeter.

The temperatures of the issuing flue gases were determined by means of mercury thermometers having compressed nitrogen in the space above the mercury, so as to prevent the boiling of the mercury.

Samples of the flue gases were collected and sent to Mr. Fletcher's laboratory in sealed tubes for analysis.

The water measurement was effected in two iron tanks, holding 167 gallons each, these being filled and emptied alternately.

The coal used was weighed in hundredweights at a time.

The smoke observations were carried out in the following way: Observers were stationed at points where a clear and unobstructed view could be obtained of a number of chimneys. The observer recorded the smoke number for each chimney at intervals of one minute during the ten hours of the test. The results were entered in narrow columns, the figures used being 3, 2, 1 and a dot, the meanings attached to these being "dense," "medium," "faint" and "no smoke," the estimation of these different densities for each observation being left to the discretion of the observer.

DEDUCTIONS FROM SMOKE OBSERVATIONS.

Of all the smoke observations made on 179 chimneys the general average in minutes of dense smoke per day of ten hours comes out to be 102, the worst case being 423 and the best four.

In hand-firing, where methods are used to admit air either at the front or back, or both, the averages in three classes of twelve examples each were 104, 81 and 82 minutes respectively, or a general average of 89 minutes' smoke. In addition to these are ten examples of front admission with side firing, where the average smoke comes out to be only 40.

The smoke averages for four kinds of sprinkling stokers used are not good, being 97, 103, 117 and 108, or a general average for sprinklers of 106 minutes of smoke.

Of the coking stokers there were seven kinds tested, these giving a smoke average of only 16 minutes.

In concluding their report the committee state that "in the great majority of cases the black smoke thrown into the air during the combustion of coal is preventable, either by hand or mechanical firing, and without great cost to the consumer. Often the prevention of smoke is accompanied with a saving of expense, in that an increase of heat is developed by a more perfect combustion of the fuel, and where live fire bars are adopted, that is, where the bars have an automatic reciprocating motion, an inferior and cheaper quality of coal can be used, and thus a further saving of expense effected"; and "the suppression of the smoke nuisance means an increased pleasure in life, and would unquestionably add to the health and wealth of the community".

The committee finally sum up their convictions as follows:—

"A manufacturing district may be free from manufacturing smoke—at least from the steam boilers, with which alone the committee have concerned themselves; and as to the means by which it may be so freed this report contains ample information."

Before coming to the extracts from the tables of results it will be useful to also mention a few facts contained in the report, which were not obtained as the direct result of the committee's tests, but from enquiries from outside sources of information.

At Messrs. Brunner and Mond's chemical works over fifty boilers are fired by Vicars' stokers, an arrangement which renders the chimneys almost smokeless; and, in addition to these, a large number of furnaces are fired with a complete absence of smoke, with Mond producer gas generated in a central station.

Mention is made of a statement by the late Mr. L. E. Fletcher that smoke might be very largely prevented, and without loss of economy, by extreme care in side-firing, with a judicious admission of air at the front and at the bridge, so long as the draught was good. In the tests which led Mr. Fletcher to hold this opinion, the average smoke for fourteen works was as low as sixteen minutes' smoke in ten hours. The method of observing the smoke was the same as that used by the Manchester committee. It is noteworthy that the smoke was much lower than in the case of the Manchester tests, and, eliminating all other sources of difference, the only explanation is, apparently, that the care taken by the firemen is less now than it was then, showing that this lessened care is due to lessened demand for careful firing.

From careful investigations made by a similar committee in Glasgow the following conclusions were arrived at :—

> "The committee are of opinion that, whilst future experiments and inventions may be the means of introducing new and better methods of treatment in the combustion of fuel, enough is known at present to enable steam users to work their boilers with a fair degree of economy and practically without smoke."

In 1893 a sub-committee in Sheffield concluded a report on smoke-preventing appliances with the following words :—

> "Whilst it is certain that smoke may be almost entirely and completely prevented from steam boiler chimneys, the conditions of working are so varied that no single arrangement can be expected to meet every individual case, and further, whatever device is applied to a boiler to prevent smoke, its success will in a great measure depend upon the intelligent handling and management which it receives on the part of those to whose care it is trusted."

Some further tests made for this same sub-committee led Mr. B. Morley Fletcher, who made the tests, to state "that, with due care on the part of the boiler attendants and the aid of apparatus suited to the particular conditions of working, smoke may be absolutely prevented throughout the whole day's working ; and furthermore, that the addition of suitable gear for combating the smoke nuisance results invariably in a gain, however small, to the consumer. In some cases the gain is by no means small, for in making the necessary improvements the efficiency of combustion within the furnaces

ABRIDGED SUMMARY OF BOILER TESTS AND SMOKE OBSERVATIONS.

Kind of grate used and conditions of firing.	Efficiency of boiler per cent.	Carbon dioxide in flue gases per cent.	Black smoke per ten hours in minutes.
COMMITTEE FOR TESTING SMOKE-PREVENTING APPLIANCES.			
Doors ajar, side firing	60·1	8·0	40·0
Grids always open	59·5	10·1	104·0
Broadbent's louvres	56·6	9·4	105·0
Split bridges and hollow bars	63·6	10·6	101·0
Grids or louvres and split bridge or hollow bars	59·0	9·7	82·0
Cass coking stoker	71·2	12·2	17·0
Crum coking stoker	68·9	10·3	Almost none
Hodgkinson coking stoker	58·0	6·73	19·0
Sinclair coking stoker	55·5	9·3	—
Vicars coking stoker	61·5	8·0	43·0
Bennis sprinkling stoker	58·3	7·9	97·0
Hodgkinson sprinkling stoker	—	—	103·0
Proctor sprinkling stoker	61·7	8·5	117·0
Whittaker sprinkling stoker	—	—	108·0
SHEFFIELD STOKING COMPETITION.	Equiv. evap. at and from.		
(*a*) Fired on double alternate system	7·95	—	19·8
(*b*) Fired on spreading system	7·89	—	33·5
(*c*) Fired on alternate system, with thin fire	8·07	—	35·9
(*d*) Spreading system, thick fires	7·43	—	30·9
(*e*) Even firing, fire very thick	9·03	—	90·8
PARIS SMOKE TRIALS.	Efficiency of boiler per cent.		Comparative smoke number.
Vertical German grate	68·9 and 71·0	9·2 and 8·5	0·25
English mechanical stoker	65·5 ,, 68·3	9·0 ,, 9·7	0·63
Double grate	67·0 ,, 70·3	8·2 ,, 9·7	2·10
Two superposed grates	76·4 ,, 73·0	5·5 ,, 7·3	2·30
French inclined grate	74·4 ,, 67·0	11·5 ,, 11·4	2·50
Powdered coal, German system	71·6 ,, 68·3	9·8 ,, 10·7	3·30
Steam jets drawing in air	71·0 ,, 69·6	9·1 ,, 10·5	3·90

is raised and results generally in an increase of evaporation per pound of fuel; and often, too, the improvements permit of the consumption of an inferior and cheaper kind of fuel, which under previous conditions would not be practicable."

The Health Committee in Sheffield adopted the suggestion made by the Smoke Abatement Committee, as one result of their investigations, that the limit to the amount of smoke to be emitted should be as follows:—

For one boiler	2 minutes per hour
For two boilers	3 ,, ,, ,,
For three or more	4 ,, ,, ,,

The above tables are intended to show the reader what kind of results may be expected from the combustion of coal on boiler furnaces of various types with different kinds of firing, both as regards economy and the quantity of smoke emitted. The figures in the different columns require some little explanation.

First Column.—In this the kind of grate and conditions of working are briefly stated.

Second Column.—The efficiency of the boiler, meaning the number of thermal units in every 100 made use of in evaporating water, the units making up the difference being wasted in various ways, chiefly in the furnace gases.

Third Column.—The percentage by volume of carbon dioxide contained in the flue gases as determined by chemical analysis.

Fourth Column.—In the second and third columns the results are those obtained in the ten-hour tests. The smoke results as given here are those obtained when observations were made of the chimney tops unknown to the firemen. Records were taken of all grades of smoke, but the figures represent the number of minutes of black smoke in the ten hours, all the other grades being reduced to that of dense smoke and the whole added together.

In the Sheffield stoking trials no "boiler efficiency" is given, but instead are the number of pounds of water evaporated at and from 212° per pound of coal.

In the Paris trials the figures given for the smoke are only comparative, being representative of the area of black smoke on the plotted smoke diagram per pound of water evaporated. This makes it impossible to compare these results with those made by the other authorities.

Furnaces other than Boilers.

The Committee further say that they are of opinion that *domestic fires are largely responsible for a smoky atmosphere*, even in manufacturing districts.

The committee go on to point out how what has been considered indispensable black smoke, in connection with puddling furnaces and furnaces used for chemical processes, may easily be dispensed with by the introduction and use of gaseous fuel instead of coal. Instances are given of the use of gas-firing at the steel works of the Pather Company's works and at those of the Glasgow Iron and Steel Company, both at Wishaw. In these cases the chimneys were practically smokeless and the furnaces were working much more economically than previously when coal fires were used. Further instances are given of smokeless gas firing at Messrs. Nettlefolds and at the Lancashire and Yorkshire Railway works at Horwich.

PRUSSIAN SMOKE COMMISSION (1894.)

The work of this commission consisted in testing seven boilers, and in these tests a number of smoke-preventing appliances were tested, careful observations of the smoke produced being made all through the trials. An elaborate photometric method was employed for determining the intensity of the smoke contained in the flue gases at any moment. Two holes were made on opposite sides of the flue leading from the boiler to the chimney, and sights were taken from one side to observe the appearance of the light at the other opening. This appearance was compared with a standard light from a candle, by means of a photometer. The method appears at first sight too elaborate, and requiring the use of costly and not very portable appliances, which would render its use out of the question for ordinary workaday smoke tests. The boilers used were Lancashire, Cornish, tubular, and tubulous; most of the grates were of German design. The conclusions arrived at by the committee do not appear to throw a great deal of light as to the best kind of grates to use, as they are all reported to be about equally good or bad, the preference, if any, being given to the Donneley and Tenbrink grates, which have already been described. It may again be stated that the former consists of two layers of vertical bars between which is the fire. The fuel is fed in from above, and the air for combustion passes horizontally into and through the burning fuel. The front bars are of the ordinary kind, while those at the back of the fire are water tubes connected with the water space. This grate is said to be very efficient as regards both economy and smoke, but its construction renders it very liable to frequent repairs; the Tenbrink is a sloping grate, arranged at an angle of about 45°; the bars are arranged in steps and the fuel is fed in through a hopper on to the dead plate at the top, and gradually works downwards, the ash and clinker reaching the bottom. It is said to be a rather costly appliance, and also one involving a large amount of labour in working.

Mr. Hale's Report on Stoking.

A most valuable report relating to the question of the cost of stoking in different cases was, in 1897, presented to the Steam Users' Association in Boston, U.S.A., by Mr. Hale, formerly their engineer. In doing this he sent out circulars to a number of persons using boilers with and without mechanical stokers, asking for information on certain points, this information being derived from their own experience. The information contained in the replies may be summed up as follows: Mechanical stokers may be said to effect a saving in labour of from 30 to 40 per cent. in very large installations; a saving of from 20 to 30 per cent. in fairly large plants; but in very small installations there is absolutely no saving in labour. Further, that in small plants having from 25 to 190 square feet grate area, one man can attend to an engine as well as fire about ten tons of coal per week; where there is an engineer and a night man, one man can fire up to about thirty-five tons per week; and, under similar conditions, two men can fire up to about fifty-five tons per week.

The important conclusions to be derived from Mr. Hale's investigations are that for large installations mechanical stokers effect a considerable saving in labour; the working of a good mechanical stoker in good condition *is practically smokeless;* a mechanical stoker is best suited for cases where the supply of steam required is fairly constant, as the firing under these conditions cannot be forced.

It may also be added that where steam jets are used in addition to the mechanical apparatus of the stoker, as in

Meldrum's stoker, it is possible to increase the evaporation to a considerable extent.

When a boiler owner is considering the advisability of substituting a mechanical stoker for hand-firing, he must, in addition to the points already mentioned, consider—

The annual interest on the first cost, and compare it with the economy he is expected to effect by the saving in labour.

The probable annual cost in repairs for the mechanical and hand methods.

The annual depreciation of the stoker.

The amount of coal burnt annually by stoker and by hand-firing.

PARIS SMOKE TESTS (from 1894 to 1897).

In the year 1894 a most valuable series of experiments were undertaken by the municipality of Paris for the purpose of ascertaining how far it was possible with the appliances at present available to work boilers efficiently and at the same time with the emission of very little smoke. It is impossible here to go into the report of the trials very fully, but the following facts, obtained from Mr. Bryan Donkin's abstract of the report, are important and exceedingly instructive.

In all one hundred and ten appliances were tested, these consisting of mechanical stokers, grates with injections of steam and air, grates with admission of supplementary supplies of hot or cold air, appliances for thoroughly mixing the products of combustion and the air, appliances for burning gaseous fuel, grates fired with powdered fuel, smoke washers, and thirty-seven classed under the indefinite head of "miscellaneous".

Two important conditions were insisted upon: Each apparatus was—

1. Not to give off an inconvenient amount of smoke when fired with ordinary fuel.
2. To satisfy the practical requirements of combustion and evaporation in steam boilers.

The official tests were made on three elephant boilers belonging to the city, and used for providing steam to drive two pumping engines. Each apparatus was placed on one of the boilers and tested for one month, but the official trials only extended over four days, two at half-load and two at full-load.

The fuel used in these tests was the same in all cases, in order to make the conditions as uniform as possible, and consisted of briquettes made from coal in the north of France. The composition of these was sensibly constant, and they contained 8·17 ash and 17·84 per cent. volatile matter. The test began each day at 8 A.M. and ran till 6 P.M., thus occupying ten hours. Full observations were taken of the quantity of fuel burnt, the quantity of water evaporated, with all the accompanying minor observations, and, in addition to these, very careful observations were taken of the amount of smoke emitted at all times during the test.

The method of taking the smoke readings is interesting. Two observers were employed, each placed at a window about 1,000 feet from the chimney, in positions so chosen that one of the two at all times was able to have a side view of the stream of gases as they issued from the top of the chimney. Five degrees of smoke were noted, as follows:—

1. No smoke.
2. Slight smoke.
3. Medium smoke.
4. Black smoke.
5. Very thick smoke.

These were recorded continuously on a rotating drum, which was driven by clockwork. The paper on the drum was divided by lines parallel to the axis into minute divisions, each of these being one millimetre wide; and by circumferential lines into five divisions, these corresponding to the five degrees of intensity of the smoke. The observer moved a marking pencil at each minute to the top of the division corresponding to the intensity of the smoke at that moment. In this way a continuous curve was drawn, from the area of which, at the end of the trial, a comparative number could be calculated, which would be an expression of the efficiency of the apparatus used as a smoke preventer. The marking pencil was attached to a sliding carriage which could be moved in a direction parallel to the axis by the hand of the observer. A sketch of the apparatus is shown in Fig. 45.

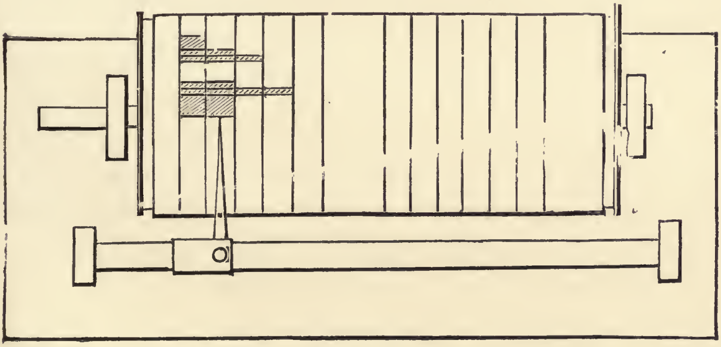


FIG. 45.—Paris Smoke-recording Apparatus.

The fact that the two observers obtained results which were very nearly coincident shows that this plan of taking smoke observations is very reliable, and might with advantage be used in this country for trials extending over any length of time.

Three prizes were offered for competition, of the values of £400, £200 and £80 respectively. The first prize was not awarded, as the committee did not think any one appliance was worthy of it, but the second prize was given to Mr. Proctor for his mechanical stoker and to M. Donneley for his vertical grate, equally. Of these, M. Donneley's was the better as regards smoke, but the judges regarded the mechanical stoker tested as the best all-round apparatus, taking into consideration both the smoke and the economical firing and freedom from want of repairs.

The authors of the report held it to be proved by their experiments that the common idea that hand firing can be managed with a little care so that no smoke is emitted is erroneous, and that it was conclusively proved that in all cases hand firing was more smoky than machine firing. Another idea which is prevalent, namely, that the production of smoke is necessarily accompanied by a corresponding waste in the shape of unconsumed carbon, was also held to be conclusively disproved. It was further shown that in very many cases smokelessness is accompanied not with a saving of fuel, but with a distinct waste, because many of the conditions necessary for smokeless firing, such as a large excess of air at certain times and at certain parts of the furnace, are just those which are conducive to the carrying off of too much waste heat.

These last conclusions are important and instructive.

REPORT OF H.M. CHIEF INSPECTOR OF ALKALI WORKS (1889).

In this report, published in 1889, special reference is made to the subject of smoke abatement.

The first point to which attention is drawn is that of the popular fallacy with regard to carbonic oxide or carbon monoxide. An idea which had obtained wide currency appears to be that it was a mistake to insist too strongly on the total absence of smoke from a boiler chimney, for the reason that the presence of some smoke was a guarantee of the absence of a much worse evil in the shape of the very poisonous gas, carbon monoxide. The idea is a fallacious one. It is possible in some cases to have CO present without smoke, and it is also possible to have it along with smoke ; this latter is a much more frequent occurrence. When CO is given off from a boiler furnace it is generally due to a deficiency of air, and this is also the most frequent cause of a smoky chimney. When special precautions are taken to do away with the smoke, the end is most frequently attained by carefully regulating the air supply, and especially to provide an increased supply after firing and during the volatilisation of the hydrocarbons. It is usually an insufficiency of air to burn the CO as it is formed that is the reason of the presence of any of the gas. The conditions necessary for the prevention of smoke and those necessary for the burning of all the CO produced are in most cases coincident, and it is therefore strange that the popular fancy should associate dense smoke with the absence of CO.

The chief inspector in his report pointed this out, but expressed the opinion that to those who were not able to follow the details of the combustion of the fuel the best proof of the freedom of flue gases from CO with smokeless firing was that of actual chemical analysis of the gases. He, therefore, gives in this report some fifty-two complete analyses of flue gases taken from boilers working with all kinds of grate and under greatly varying conditions. In very few cases is CO found at all, and when so found it is generally where the presence of black smoke indicates an imperfect combustion. And when the air supply has been sufficiently large to admit of the emission of no smoke, carbon monoxide has also ceased to be present, thus showing that the conditions necessary for freedom from black smoke are coincident with those necessary for the perfect combustion of the carbon and the non-existence of carbon monoxide.

Further, it is stated that in some cases where black smoke was emitted there was carbon monoxide present also, but in all cases where the smoke was absent the carbon monoxide was absent also. In the words of this report, "there was no exception to this rule". The report is accompanied by the full details of all the analyses.

Reference is made to the natural advantages which mechanical firing has over ordinary hand firing, and the advantages of burning gaseous fuel in place of coal are set forth in some detail, mention being made of the producers and systems of Siemens, Wilson, Strong, Dowson, Blass, Thwaite, Sutherland and others; and one or two new forms of boiler furnace, approximating to combined producers and furnaces, are mentioned. These latter are chiefly in use on the Continent.

CHAPTER VIII.

THE LEGAL ASPECT OF THE SMOKE QUESTION.

It is not the intention of the writer to attempt an exhaustive discussion of a subject which presents peculiar difficulties, but simply to place the facts as to the law relating to the smoke nuisance before the reader, and with such brief comments as may be necessary.

That the present method of dealing with smoke cases is defective must be admitted on all sides. The law is there, both in a general Act of Parliament and in a number of local Acts. Many owners of factories are being prosecuted every week, but the fact remains that, although the atmospheres of our manufacturing towns may be to some extent more free from smoke than they were twenty years ago, the progress made has been lamentably deficient and not at all commensurate with the work that has been done.

The general Act of Parliament which may be made use of by local authorities in carrying out prosecutions is the Public Health Act of 1875, and an inspection of the sections and clauses given below, and which may be taken as bearing on the subject of smoke abatement, will make it clear that it lies within the power of a local authority, a private individual or a local authority outside the district where the offence is committed, to set in motion proceedings against any person who is deemed to be committing a nuisance by allowing the emission of black smoke from the chimney of his factory or workshop. On receipt of information as to the supposed nuisance the local authority is expected to serve a notice of abatement on the offender, and in case of non-compliance with this notice the authority must take out a summons before a court of summary jurisdiction. And, further, where the local authority is not satisfied with the ruling of this court, and is satisfied that justice has not been done, power is given, under Section 107, to take the cases to superior courts.

Below is set forth Section 91 of the Act referred to, this being the chief part referring to the subject under discussion, and a number of other sections are given in full, or in part, or are referred to briefly.

Sub-section 7 (relating to smoke prevention) of Section 91 of the Public Health Act, 1875, runs as follows :—

" Any fireplace or furnace which does not as far as practicable consume the smoke arising from the combustible used therein, and which is used for working engines by steam, or in any mill, factory or dyehouse, brewery, bakehouse or gas work, or in any manufacturing or trade process whatever, and any chimney (not being the chimney of a private dwelling house) sending forth black smoke in such quantity as to be a nuisance, shall be deemed to be a nuisance liable to be dealt with summarily in the manner provided by this Act : provided—

" 1. That a penalty shall not be imposed on any person in respect of any accumulation or deposit necessary for the effectual carrying on of any business or manufacture, and that the best available means have been taken for preventing injury thereby to the public health.

" 2. That where a person is summoned before any court in respect of a nuisance arising from a fireplace or furnace which does not consume the smoke arising from the combustible used in such fireplace or furnace the court shall hold that no nuisance is created within the meaning of the Act and dismiss the complaint if it is so satisfied that such fireplace or furnace is constructed in such manner as to consume as far as practicable, having regard to the nature of the manufacture or trade, all smoke arising therefrom, and that such fireplace or furnace has been carefully attended to by the person having the charge thereof."

Section 92.—The title runs: "Duty of local authority to inspect district for detection of nuisances".

Section 93.—Information of nuisances to the local authority may be given "by any person aggrieved thereby, or by any two inhabitant householders of such district, or by any officer of such authority, or by the relieving officer, or by any constable or officer of police force of such district".

Section 94.—On receipt of information of nuisance the local authority, if satisfied of its existence, shall serve notice of abatement within a specified time on the person by whose act, default or sufferance the nuisance arises, and require him to execute the necessary works.

Section 95.—On non-compliance with the notice from the urban or rural authority a summons shall be taken out by that authority before a court of summary jurisdiction.

Section 96.—If the court is satisfied that the alleged nuisance exists, or that, although abated, it is likely to occur on the same premises, the court shall make an order requiring compliance with the notice of the authority, or prohibit the recurrence of the nuisance or both, and may impose a penalty not exceeding £5, and shall give direction as to costs:

Section 98.—Penalty imposed, not exceeding 10s. a day, for not obeying the order of the court if the defendant fails to satisfy the court that he has used at all times all diligence to carry out the order. In these cases the evidence of experts may be required to show what might have been done.

Section 102.—This section refers to the powers of the local authority to enter any premises from which a nuisance proceeds, or to obtain a magistrate's order in cases where admission is refused.

Section 105.—This "enables any individual aggrieved by a nuisance, or any inhabitant of, or any owner of premises in the district to complain to a justice, whereupon the proceedings by summons, order of abatement, etc., will be the same as though the local authority itself were the complainants".

Section 106.—"Where it is proved to the satisfaction of the Local Government Board (London) that a local authority are neglecting their duty in the suppression of a nuisance, the Local Government Board may authorise any officer of police to act in the place of the local authority."

From this section we gather that it is quite possible for any individual who is not satisfied as to what is being done by the local authority for the suppression of smoke to make a definite statement of all the details of the case, and the Local Government Board will then have to respond and make full enquiries into the case.

Section 107 gives powers to the local authority to take cases to superior courts to enforce the abatement or prohibition of a nuisance when in their opinion the proceedings before the local magistrates have not yielded a satisfactory solution of the difficulty.

Section 108.—In this section power is given to a local authority to proceed against a nuisance which appears to be partly or wholly caused by acts committed outside its own district. The case must, however, be tried in a court in the district where the fault has been committed or in a superior court.

Section 334.—"Nothing in this Act shall be construed to

> extend to mines of different descriptions so as to interfere with or to obstruct the efficient working of the same; nor to the smelting of ores or minerals, nor to the calcining, puddling and rolling of iron and other metals, nor to the conversion of pig iron into wrought iron, so as to obstruct or interfere with any of the processes respectively."

Besides this general Act, which may be made use of by any local authority whatever, there are many sections and clauses of local Acts which are made use of, either in place of the Public Health Act or in conjunction with it, according to the fancy of the authority in question.

The Act is not specific as to what amount of smoke constitutes a nuisance, and this point is left to be decided by the court before which the case is tried. In order to make the offence of a more definite and specific kind, some authorities have formed bye-laws of a more or less stringent character relating to the quantity of black smoke which may be emitted in a given time. These rules show great divergence of opinion among the different authorities as to what does constitute a nuisance. For instance, in Bolton (Lancs.) a fine is imposed if for more than three minutes in the half-hour or six minutes in the hour dense, black smoke is seen to issue from a chimney; whereas in Oldham the authorities are more lax and allow twelve minutes in the hour of dense, black smoke. There is also great difference in the way the density of the smoke is defined and as to what exactly constitutes black smoke. The fines imposed are in many cases quite inadequate, and have very little effect in tending to deter the offenders from allowing the nuisance to continue.

In London, perhaps more than anywhere, has the smoke nuisance been properly approached. This is in a great measure due to the fact that the matter is put into the hands of the police, who are empowered to report any chimneys that they deem to be unduly productive of smoke. By this arrangement the chimneys are liable to be reported on at any moment, and the effect of introducing this strong manner of dealing with the question has been to bring about results far ahead of any that can be recorded in the more exclusively manufacturing centres. And it is not that there are few industrial chimneys in London, for it is well known that in certain districts the number of boiler and other furnaces is very great. If London can deal with the trouble, it ought surely to be possible for the great industrial communities to do as much.

In order to give the reader definite information as to the means adopted by our local authorities for the abatement of the smoke nuisance, the writer submits the following details relating to the methods observed by the authorities of a number of the chief towns and cities in Great Britain. In many cases local Acts are made use of, either alone or as supplementary to the Public Health Act. Several of these Acts are given so far as the sections relating to the smoke nuisance are concerned. It will be seen that, both as regards the general methods of procedure and in respect to the legal powers employed, there is a great deal of variety. Very few towns are alike in these respects. It is a great pity that this is so, because the local conditions cannot possibly affect the emission of smoke to any appreciable extent, and it would be much more satisfactory if a general set of regulations could be framed which would be applicable to all parts of the country.

BOLTON (LANCS.).

In this town proceedings are taken under the Local Government Provisional Orders Confirmation (No. 15) Act, 1893, section ii., sub-section 2. Sub-sections 1 and 2 are given in full below.

When an inspector sees a chimney sending out black smoke in large quantities he makes a note in his pocket-book, and, as soon after as possible, he takes a thirty minutes' observation, recording the particulars in his smoke note-book. The heading of a page of this book is as follows :—

Date.. *Page*..........................

Name of Firm...

....

Description of Works..

Situate in...

No. of Observation..................*No. of Boilers*.................

Place of Observation..

Time.	Black Smoke, M.	Remarks.

If black smoke issues for as much as two and a half minutes in the half hour, or at the rate of five minutes in the hour, the inspector then makes out an observation memorandum and leaves it at the works. This form is as follows :—

COUNTY BOROUGH OF BOLTON.
BLACK SMOKE OBSERVATION.

OWNER..
DESCRIPTION OF WORKS } ....
AND WHERE SITUATE } ....
DATE...
TIME ....
DURATION OF BLACK SMOKE..MINUTES.
....INSPECTOR.

While at the fireplace the inspector makes a note of what he sees and is stated to him, especially with regard to the smoke-preventing apparatus, number of boilers available, number of boilers working, etc. The instructions given to the inspector and the details of the information obtained are shown below.

Smoke Observations.

"The Medical Officer of Health will be glad if the inspectors will obtain information under the following headings in each smoke observation, and enter the same in the smoke pocket-books:—

1. Factory or workshop (registered office).
2. Chimney.
3. Number of boilers.
4. Number of boilers at work.
5. Number of furnaces to each boiler.
6. Mechanical apparatus used on each furnace.
7. Mechanical stokers.
8. Whether in working order.
9. Whether hand-fired.
10. Name of fireman.
11. Does he attend engine as well.
12. Direction of wind.
13. Remarks.

"During an observation no notice is taken of emissions of less than half a minute."

The nuisance is entered in the smoke observation note-books and records, and as soon as possible after this the council notice to abate is served. In the report books full particulars are entered of the name of the firm, situation, date, time during which black smoke is seen, direction of wind, state of atmosphere, name of inspector, etc. Separate books are kept for nuisances for notices, nuisances for prosecution. Complete details of all observations, and the full account of observations, notice, prosecution and penalties imposed in the case of each firm dealt with are summarised in other books.

If the emission of black smoke is repeated after the notice to abate has been served, the sanitary committee at their next meeting authorise the medical officer of health to take proceedings.

The following is the form used in sending the notice of abatement:—

"NOTICE AS TO CHIMNEY SENDING FORTH BLACK SMOKE.

BOLTON CORPORATION ACT, 1872.

Local Government Board's Provisional Orders Confirmation (No. 15) *Act,* 1893.

To

"WHEREAS, on the day of , 189 , from a certain chimney not being the chimney of a private dwelling-house, to wit, the chimney of Mill, situate in or near Street in the said Borough, black smoke was emitted in contravention of the provisions of Article II. (2) (A) of the Bolton Order, confirmed by the above-mentioned Act, in such a quantity as to be a nuisance [where the best practical means for preventing such emission are not in use],

"Now the Mayor, Aldermen and Burgesses of the Borough of Bolton, in the County of Lancaster, pursuant to the provisions of the above-mentioned Acts, do hereby give to you as owner or occupier of the land on which the said chimney is situate, notice to discontinue such emission of black smoke as aforesaid, and do further give you notice that if after the service hereof such emission is repeated you will be liable to a penalty not exceeding five pounds for each such offence, and on each subsequent conviction to a penalty not exceeding twenty pounds.

"DATED this day of , 189 .

R. G. HINNELL,
Town Clerk.

"Duplicate of this notice served by me this day of , 19 , by sending the same prepaid through the General Post Office at Bolton addressed to

(Signed)

Chief Clerk."

The following is the full text of the Act of Parliament under which action is taken by the corporation of Bolton:—

LOCAL GOVERNMENT BOARD'S PROVISIONAL ORDERS CONFIRMATION (NO. 15) ACT, 1893.

Section 2, *Sub-section* 1.—(*a*) If any fireplace or furnace for the time being employed within the borough in the working of engines by steam (not being a locomotive engine used on the railway of any company incorporated by Act of Parliament), or used for the purposes of trade or manufacture, or baths or wash-houses (although a steam engine is not used or employed therein), is not so constructed as to consume or burn the smoke arising from such a fireplace or furnace, the owner or occupier of the building or land in or on which such fireplace or furnace is situate shall be liable to a penalty not exceeding ten pounds.

(*b*) If any such owner or occupier uses any such fireplace or furnace not so constructed as aforesaid, or if any such owner or occupier, or any engineer, fireman, stoker, foreman or other person employed by such owner or occupier negligently uses any fireplace or furnace so constructed as aforesaid in such manner that the smoke arising therefrom is not effectually consumed or burnt he shall be liable to a penalty not exceeding ten pounds, and to a further penalty not exceeding forty shillings for every day during any part of which such fireplace or furnace is so continued to be used after one month's notice, in writing, given by the corporation to the owner or occupier to remedy or discontinue the same.

(*c*) If any such owner or occupier refuses to allow such building or land to be inspected by a person authorised by the corporation then any person so authorised may, by warrant under the hand of a justice (which warrant any justice is hereby authorised to grant), enter into and upon such building or land and examine any such fireplace or furnace.

Provided that these provisions shall not be held in all cases to mean that it shall be necessary to consume or burn all the smoke, but the court hearing an information or complaint against a person shall dismiss the information or complaint if of opinion that such person has so constructed his fireplace or furnace, or fireplaces or furnaces, as to consume or burn *as far as practicable* all the smoke arising from such fireplace or furnace, or fireplaces or furnaces, and has carefully attended to the same, and consumed or burned as far as possible the smoke arising from such fireplace or furnace, or fireplaces or furnaces.

Sub-section 2.—(*a*) If from any chimney, not being the chimney of a private dwelling-house, black smoke is emitted either in such quantity as to be a nuisance, or where the best practicable means for preventing such emission are not in use, the corporation may, on complaint by any person aggrieved or by two inhabitant householders of the borough, cause notice to be given to the owner or occupier of the land on which such chimney is situate, or to the owner or occupier of the furnace or fireplace in connection with which such chimney is used, to discontinue such emission, and if after such notice the emission is repeated such owner or occupier shall for each such offence be liable to a penalty not exceeding five pounds, and on each subsequent conviction to a penalty not exceeding twenty pounds.

(*b*) Where more fireplaces or furnaces than one communicate with a single chimney, or a chimney is used with more fireplaces or furnaces than one, the names of the several owners or occupiers of the buildings or land on which such fireplaces, or furnaces, or chimney are situate may be included in one summons, and the justice or justices before whom the case is brought may in his or their discretion apportion the penalty between the several owners or occupiers, as the case may be, or impose a penalty on one or more of such owners or occupiers to the exclusion of the others.

BRISTOL.

In Bristol there are no special smoke inspectors, the matter being dealt with by the inspector of nuisances as representing the Public Health Department. There are no special local Acts or bye-laws available, and any action must be taken under the Public Health Act of 1875.

CARDIFF.

Here there is no special local Act of Parliament, but any steps that are taken are under the Public Health Act of 1875.

Apparently, from what the writer can learn, there is little trouble in Cardiff with regard to the smoke nuisance.

EDINBURGH.

In this city the smoke nuisance is dealt with by the burgh engineer, who, on receipt of a complaint as to the emission of smoke, sends out two inspectors. These take observations for periods ranging from two to four hours. The result of the observations is reported to the burgh engineer, who, in the case of a first offence, writes to the offenders, and points out that a complaint has been made, and encloses a copy of the notice which is given below. In making their inspection the inspectors take the firemen in hand, and, from their own knowledge and experience, are able to give such advice and instruction that a great improvement is generally effected.

In the case of a second complaint, and after making further observations to test the validity of the complaint, action is taken by the public prosecutor in a local police court.

Besides action taken in this way as the direct result of complaint, inspectors are constantly engaged in overlooking all the works and manufactories throughout the city.

Legal action is taken under the sections of local Acts given below.

In addition to these a copy is given of the notice sent out. The notice and the copy of the sections of the Acts are printed on the same sheet.

Section 295 of The Edinburgh Municipal and Police Act, 1879.

" 295. Every furnace employed or to be employed in the working of engines by steam, or in any mill, factory, dyehouse, iron foundry, glasshouse, distillery, brewery, gaswork, or other building used for the purpose of trade or manufacture, shall be constructed so as, so far as practicable, to consume or burn the smoke arising from such furnace ; and every person who shall use any furnace which shall not, so far as practicable, be so constructed and used as that the smoke arising therefrom shall, so far as practicable, be effectually consumed or burned, or shall carry on any trade or business which shall emit any effluvium offensive or injurious to the health of the inhabitants in the neighbourhood of the premises in which such trade or business is carried on, shall be liable to a penalty not exceeding five pounds for and in respect of every day or part of a day during any portion of which such use of such furnace or such emission shall be continued, after one month's notice shall have been given by the Magistrates and Council to remedy or discontinue the same."

Sub-section 3 *of Section* 87 *of The Edinburgh Improvement and Tramways Act*, 1896.

"Section 295 of the Act of 1879 shall be read as if the following proviso were added at the end thereof: 'Provided always that where the emission of black or brown smoke from any furnace or fire is caused by excessive, careless, or inefficient firing, or by the mismanagement of any furnace or fire, the liability for the said penalty shall be incurred on conviction, without service of any notice or requirement for its discontinuance or remedy being necessary'."

Section 65 *of The Edinburgh Improvement and Tramways Act*, 1896.

"Every new and every existing chimney stalk or flue connected with the furnace of a steam boiler or other furnace for commercial or manufacturing or other purposes shall be built of sufficient height to carry off the smoke and other products of combustion without offence to the occupiers of neighbouring houses or buildings, and the Dean of Guild Court may, on the application of the master of works or any person interested after giving parties an opportunity of being heard, issue an order requiring the owner of any such chimney stalk or flue (new or existing) to raise the same up to a height sufficient, in the opinion of the said court, to carry off the smoke and other products of combustion, as aforesaid, and such owner shall, on failure to comply with such order, be liable in a penalty as hereinafter in this Act provided."

COPY OF NOTICE.

BURGH ENGINEER'S OFFICE,
POLICE CHAMBERS,
EDINBURGH,..189

To..

SMOKE NUISANCE.

SIR,

I beg to direct your attention to the further powers obtained by the Magistrates and Council of the City of Edinburgh, under section 87, sub-section 3, and section 65 of The Edinburgh Improvement and Tramways Act, 1896 (see third page), whereby it is provided and enacted that liability to the penalty applicable to emissions of smoke caused by excessive, careless, or inefficient firing is incurred on conviction without service of any notice or requirement for discontinuance or remedy being necessary.

I am, Sir,
Your obedient Servant,
JOHN COOPER,
Burgh Engineer.

GLASGOW.

Here there is a local Act which provides the necessary powers under which action is taken. The section of this Act of Parliament is as follows :—

Glasgow Police (Further Powers) Act, 1892, *Section* 31.

" Every person who so uses, causes, permits, or suffers to be used, any furnace or fire within the city (except a household fire) so that smoke issues therefrom, unless he proves that he has used the best practical means for preventing smoke, and has carefully attended to and managed such furnace or fire so as to prevent, as far as possible, smoke issuing therefrom, shall be liable for the first offence to a penalty not exceeding forty shillings, and for a second or any subsequent offence, if committed within twelve months of the immediately previous conviction, to a penalty not exceeding five pounds."

The system of inspection is a thoroughly comprehensive one. When a chimney is to be observed two inspectors are deputed to take simultaneous observations from different points of view, and not in sight of one another. Evidence is given in court by each of the two without having in the meantime communicated with one another. I am indebted to Mr. Peter Fyfe, the Chief Sanitary Inspector, for a page of the inspectors' note-book which is in use in Glasgow. The page consists of a form in which spaces are provided for the insertion of information on the following points :—

Name and address of firm (against whom the complaint is lodged)..........................
Number and size of boilers..............................
Grate area and coal consumption..............................
Kind of coal used..............................

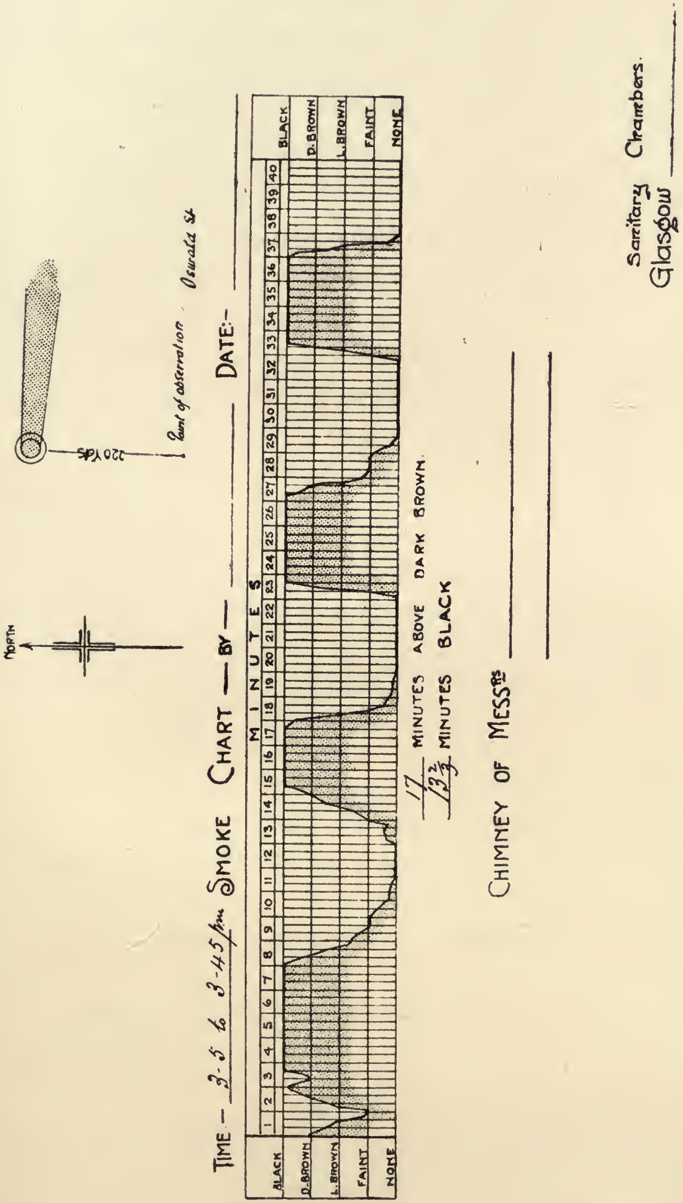
Horse-power of boilers and working pressure......................................
Dimensions of chimney...................................
Size and horse-power of engines...................................
Fireman in charge of furnace...................................
Apparatus in use for smoke prevention...................................
Supposed cause of smoke excess...................................
Warnings given and dates...................................
Convictions in police court...................................

In addition to these details is a blank form on which to plot the results of any smoke observations that are taken. These are shown below, both the blank forms from the page of the book and an example of an actual plotted chart (Fig. 46). It will be seen that five degrees of density are made use of, the density at the end of each twenty seconds being marked on the chart on its own line of reference. The points so obtained are joined by a continuous curve, with the result shown in the example given. The chart is then made use of in order to ascertain, first, the number of minutes during which the smoke was "*black*," and, secondly, the number of minutes during which it was "*above dark brown*". This is the standard form on which the results are plotted in cases of prosecution. A rough plan is attached showing the direction of the wind and the location of the point of observation.

If the different local authorities who are specially concerned in this matter would agree upon one uniform system to be used in all parts of the country the cause of smoke abatement would be helped on, inasmuch as greater facilities would then be given for the comparison of the results obtained under varying conditions and with the furnaces which may be in use at different places.

SPECIMEN PAGE OF SMOKE BOOK.

NAME AND ADDRESS OF FIRM.	
NUMBER, TYPE AND SIZE OF BOILERS.	
GRATE AREA AND COAL CONSUMPT.	
KIND OF COAL USED.	
H.P. OF BOILERS AND WORKING PRESSURE.	
DIMENSIONS OF CHIMNEY.	
SIZE AND H.P. OF ENGINES.	
FIREMAN IN CHARGE OF FURNACES.	
APPARATUS IN USE FOR SMOKE PREVENTION.	
SUPPOSED CAUSE OF SMOKE EXCESS.	
WARNINGS GIVEN AND DATES.	
CONVICTIONS IN POLICE COURT.	



TIME.– 3-5 to 3-45 p.m. SMOKE CHART — BY — DATE:-

17 MINUTES ABOVE DARK BROWN.

$13\frac{2}{3}$ MINUTES BLACK

CHIMNEY OF MESSRS

Sanitary Chambers.
Glasgow

FIG. 46.—Specimen of a Glasgow Smoke Chart.

LEEDS.

In Leeds action is taken under the sections of the local Act of Parliament which are given below. Inspectors are constantly observing the chimneys, and, if one is found to be giving out more than the specified amount of black smoke, the following brief notice is sent out to the offender :—

SMOKE INSPECTOR'S OFFICE,
MUNICIPAL BUILDINGS, LEEDS.
……………………18……

……………………………

Observations having been made of the smoke emitted from the chimney attached to your……………………
furnace situate at……………………………
in the township of……………………, I find it is far denser and blacker than it should be, and I hope you will at once adopt such means to prevent a recurrence of the nuisance as shall prove efficient without further notice.

I remain,
Yours respectfully,
……………………

If, on receipt of this, no improvement is effected, the following special notice is sent, which, if not complied with, is followed by legal action being taken before the justices.

In determining whether the smoke emitted constitutes a nuisance, it is usual to allow five minutes in the hour.

No.…………

SMOKE INSPECTOR'S OFFICE,
MUNICIPAL BUILDINGS, LEEDS.

SPECIAL NOTICE.

COUNCIL OF THE CITY OF LEEDS.

I, the undersigned,……………………………

....being an officer of the Council of the City of Leeds, duly appointed in this behalf, DO hereby give you notice that by section 70 of the Leeds Improvement Act, 1866, it is enacted that " From and after the passing of this Act every furnace employed, or to be employed in the City of Leeds, in the working of engines by steam, and every furnace employed or to be employed in any mill, factory, printing house, dye house, iron foundry, glass house, distillery, brew house, sugar refinery, bakery, gasworks, waterworks, or other buildings used for the purposes of trade or manufacture within the said city (although a steam engine be not used or employed therein), shall in all cases be constructed or altered so as to consume or burn the smoke arising from such furnace; and if any person shall hereafter within the said city use any such furnace which shall not be constructed so as to consume or burn its own smoke, or shall so negligently use any such furnace as that the smoke arising therefrom shall not be effectually consumed or burnt," and whereas you cause the nuisance referred to in the said Act by permitting or causing dense smoke to issue from the furnaces used by you in the trade or business of a..

....

THIS is to give you notice that if the said nuisance be not abated, by the alteration and construction of your said furnaces so that the smoke arising therefrom shall be effectually consumed or burnt, proceedings will be taken before the justices to recover the penalties therein provided, without further notice.

Dated this..day of.., one thousand eight hundred and .

....

....

Sections extracted from The Leeds Improvement Act, 1866. (29 & 30 *Vict.*)

"LXX. And whereas by the twenty-fifth Section of the said Act of 1856, it is enacted that, from and after the first day of March, 1857, every furnace employed in the Borough of Leeds for the purposes in the said Section mentioned, shall, in all cases, be constructed or altered so as to consume the smoke arising from such furnace, but the said enactment is so limited by various subsequent provisions as to be practically nugatory, and the nuisance arising from the smoke in the said borough not only continues, but increases to the great injury of the health of the inhabitants of the borough, and also of the vegetation and property within and in the neighbourhood of the borough: Be it enacted, that the twenty-fifth, the twenty-sixth, the twenty-seventh, the twenty-eighth, the twenty-ninth, and the thirtieth Sections of the said Act are hereby repealed, and in the stead thereof the following provisions shall be in force as follows:—

"(*a*) From and after the passing of this Act, every furnace employed or to be employed in the Borough of Leeds, in the working of engines by steam, and every furnace employed or to be employed in any mill, factory, printing house, dye house, iron foundry, glass house, distillery, brew house, sugar refinery, bakery, gasworks, waterworks, or other buildings used for the purpose of trade or manufacture within the said borough (although a steam engine be not used or employed therein) shall in all cases *be constructed or altered* so as to consume or burn the smoke arising from such furnace; and if any person shall hereafter within the said borough use any such *furnace which shall not be constructed* so as to consume or burn its own smoke, or shall *so* *negligently use any such furnace* as that the smoke arising therefrom shall not be effectually consumed or burnt, or shall carry on any trade or business which shall occasion any obnoxious or offensive effluvia, or otherwise annoy the neighbourhood or inhabitants, without using the best practical means for preventing or counteracting such annoyance, every person so offending, being the owner or occupier of the premises, or being a foreman or other person employed by such owner or occupier shall, upon a summary conviction for such offence before any justice or justices, forfeit and pay a sum not more than five pounds nor less than forty shillings, and upon a second conviction for such offence the sum of ten pounds, and for every subsequent conviction the sum of twenty pounds;

"(*b*) Provided always, That the words 'consume or burn the smoke' shall not be held in all cases to mean 'consume or burn all the smoke,' but that the justice or justices before whom any person shall be summoned shall not impose the penalties enacted by this Act if he or they shall be of opinion that so far as, in the judgment of the said justice or justices, is practicable, without damaging the article manufactured or operated upon, or rendering necessary any expenditure or inconvenience which in the opinion of the said justice or justices shall be unreasonable, such person has so constructed or altered his furnace as to consume or burn, as far as possible, all the smoke arising from such furnace, and has carefully attended to the same, and consumed or burned the smoke arising from such furnace;

"(*c*) No means for the prevention or consumption of smoke shall be deemed practicable within the meaning of this Act, as regards the application to any dye pan, dye vat, or dye vessel, used for the dyeing of wool, woollens, or worsted stuffs, or as regards the smelting of iron ores, or the refining, puddling, shingling, and rolling of iron or other metals, or the melting and casting of iron into castings, or as regards the coking of coal, or the calcining of ironstone or limestone, or the making or burning of bricks, quarries, tiles, or pipes, unless it shall be proved to the satisfaction of the justice or justices, or, in case of appeal, to the satisfaction of the court of quarter sessions, that the same have been successfully applied in similar processes, and are in actual operation, and have been used for twelve months in similar processes or in similar trades, under like circumstances;

"(*d*) All persons whatsoever making use in any buildings within the borough of fires casting up large quantities of smoke or flame, shall alter all the chimneys and furnaces which are now made, and shall construct all chimneys and furnaces which shall at any time or times hereafter be made in or in connection with any such buildings of such respective heights, not exceeding ninety feet, as the council shall order or direct, for the purpose of preventing as much as may be the same from being a nuisance, and every person who shall neglect or refuse to alter or construct his chimney or furnace according to such order or direction, for the space of three months after notice in writing for that purpose, signed by the town clerk, or any officer appointed by the council shall have been given to him or left at his dwelling-house, or at the building in which such chimney or furnace is placed, or to which the same belongs, shall forfeit and pay any sum not exceeding ten shillings for every day during which after the expiration of such three months he shall use any such chimney or furnace, which shall not have been altered or constructed according to such order and direction: Provided always, That no penalty shall be imposed on any person for any alleged offence against any such order or direction as aforesaid, unless it shall be proved to the satisfaction of the justice or justices before whom the case shall be heard, or, in case of appeal, to the satisfaction of the court of quarter sessions, that the alteration or construction of the chimney or furnace of such person required by such order or direction may be made or effected without damaging the article manufactured or operated upon, or rendering necessary any expenditure or inconvenience which, in the opinion of such justice or justices, or of such court of quarter sessions (as the case may be) shall be unreasonable;

"(*e*) If the owner or occupier of any premises to which this Act shall apply shall refuse to allow his premises to be inspected by the inspector of smoke, or if any person complaining of the issue therefrom of an excessive quantity of smoke, shall lay an information on oath before a justice of the peace, it shall be lawful for any constable or constables, authorised by warrant under the hands of two of Her Majesty's justices of the peace for the said borough, to enter, with the inspector of smoke, who shall be bound to act under such warrant, into and upon any building or premises in the said borough in which any furnace may be or in which such noxious trade or business may be carried on, and to examine into the construction of and manner of using such furnace; and any person obstructing any such constable, or his assistants, in the execution of any such warrant or order shall, upon a summary conviction for such offence before any justice or justices, forfeit and pay any sum not exceeding twenty pounds;

"(*f*) The council of the borough shall within three months after the passing of this Act appoint a fit person to be an inspector of smoke in the said borough, and shall pay to the said inspector such salary as they may from time to time determine; and may at their pleasure remove any person so appointed, and shall appoint from time to time some other fit person in the room of any inspector who shall be so removed, or who shall die or resign his office, and the salary so fixed shall be paid by the corporation out of the improvement rates to be levied in and throughout the borough;

"(*g*) It shall be lawful for the said inspector, and he is hereby required to commence and prosecute at his discretion informations or legal proceedings against any person for the recovery of any penalty or forfeiture to be incurred under or by virtue of the enactments hereinbefore contained with respect to the prevention or consumption of smoke, and that without any authority from, or reference to, the council of the borough, or any committee thereof; and the expenses reasonably incurred by the inspector in the performance of his duty shall be from time to time paid by the corporation out of the improvement rates to be levied in and throughout the borough, and it shall also be lawful for any other person to commence and prosecute at his own cost and risk any such information or proceeding, provided that such person is an inhabitant of the borough.

"LIX. The corporation from time to time may regulate the height of the chimneys of all buildings, on or at any time after the passing of this Act, used for the purposes of trade or manufacture, or for baths and wash-houses, and may by order in writing direct that any chimney shall be altered or built so that the same shall be of the height specified in such order; and any person who shall not comply with such order, or who, in the case of any new chimney, shall neglect to give seven days' notice in writing to the corporation, or their surveyor, of his intention to build the same, shall for every such offence forfeit not exceeding twenty pounds."

LONDON.

Throughout London proceedings are taken under sections 23 and 24 of the Public Health (London) Act, 1891.

MANCHESTER.

In the city of Manchester the Public Health Act of 1875 is made use of in dealing with the smoke nuisance, the actual part being sub-section 7 of section 91, and this is supplemented by section 44 of the Manchester Corporation Act, 1882. The above mentioned sub-section of the Public Health Act, 1875, has already been given. The section of the supplementary local Act, dealing with "Smoke Nuisances," runs as follows:—

> "For the purposes of more effectually carrying into effect the provisions of the Public Health Act of 1875 in respect to smoke nuisance when an order of abatement or prohibition has been made under that Act, it shall be lawful for the justices of the peace for the city to impose any daily penalty not exceeding £10 in respect of any breach or non-observance of such order."

The effect of this section is to increase the penalty from £1 to £10 (at the discretion of the justices), and it is the only section of the local Act of 1882 relating to smoke prevention.

NEWCASTLE-UPON-TYNE.

In Newcastle the smoke abatement question is in the hands of the inspector of nuisances. Legal proceedings are taken under the Public Health Act of 1875.

SALFORD.

In this borough, where there are a great number of manufactories of all kinds, legal proceedings are taken by the Health Committee of the Council, under a local Act of 1862, whose provisions are stated in the following notice, which is issued by the medical officer of health:—

Notice of Penalties for Non-consumption of Smoke, and requiring Fireplaces or Furnaces to be remedied or discontinued.

BOROUGH OF SALFORD.

CONSUMPTION OF SMOKE.

TAKE NOTICE, that, under the provisions of The Salford Improvement Act, 1862, if any fireplace or furnace, employed or to be employed within the borough, in the working of engines by steam, or in any building used for the purpose of trade or manufacture, or baths, or wash-houses (although a steam engine be not used or employed therein), shall not be so constructed as to consume or burn the smoke arising from such fireplace or furnace, the owner or occupier of the premises, on which such fireplace or furnace shall be situate, is liable to a *penalty* not exceeding *five pounds.* And that every person being the owner or occupier of the premises, or being a foreman or other person employed by such owner or occupier, who shall use any such fireplace or furnace which shall not be so constructed as aforesaid, or shall so negligently use any fireplace or furnace which has been so constructed as aforesaid, so that the smoke arising therefrom shall not be effectually consumed or burnt, is liable to a *penalty* not exceeding *ten pounds*, and to a further *penalty* of *forty shillings* for every day during any part of which such fireplace or furnace shall be so used and continued, after one month's notice, in writing, shall have been given to the owner or occupier to remedy or discontinue the same.

AND TAKE NOTICE, that a certain *fireplace* or *furnace*, employed by you in a certain
occupied by you in Street, in the said borough, is not so constructed as to consume or burn its own smoke, and that you are, therefore, hereby required by the corporation of the said borough to discontinue the use of such (fireplace or furnace), or remedy the construction thereof, and so use the same that the smoke arising therefrom shall be effectually consumed or burnt, and that in default thereof proceedings will be taken after the expiration of one calendar month after the service of this notice upon you, for the purpose of enforcing payment of the penalties aforesaid.

Dated this day of 187 .

Medical Officer of Health,
Town Hall, Salford.

In addition to this notice, which is used in specific cases, a general supplementary notice was issued in October, 1900, calling the attention of the owners to the fact that the amount of smoke issuing from the chimneys of the different works in the borough had been distinctly on the increase, and pointing out that, in the first place, there is no need for any works to produce black smoke, and that the conditions which conduce to smokeless firing are beneficial to the manufacturer ; and, secondly, that the production of black smoke is illegal under the powers possessed by the corporation in the Salford Improvement Act of 1862.

This notice further states that whereas the time allowed for the emission of black smoke had been five minutes in every hour's observation, the time of observation would be reduced to half an hour, and that works sending out smoke for more than three minutes in this time would be prosecuted.

It was also recommended that a 30 ft. by 7½ ft. Lancashire boiler should in no case burn more than twenty tons of coal per week, and if this amount is to be exceeded special mechanical appliances are necessary. This refers to hand firing, presumably with natural draught.

The committee do not recommend any special appliances, beyond stating that *coking stokers* are the most satisfactory smoke-preventing appliances.

They also lay special stress on a manufacturer having *sufficient boiler accommodation*, and state that they will prosecute the fireman and not the owner where smoke is emitted in excessive quantities and there is at the same time sufficient boiler accommodation.

All these recommendations are thoroughly sound, and the committee appear to be doing their best to deal with the smoke question under the existing conditions.

SHEFFIELD.

In Sheffield there is no local Act, but the Health Department prosecute persons allowing an excessive amount of black smoke to be emitted, under the Public Health Act of 1875.

CHAPTER IX.

THE MEANS TO BE ADOPTED FOR LESSENING THE SMOKE IN OUR ATMOSPHERE.

In the preceding chapters the conditions appertaining to combustion, the various furnaces which are in use, the special appliances which have been, and are being used for the purpose of smoke abatement, and the law relating to this question have all been discussed. It now remains to collate and sum up the various arguments, and to see in what directions good results may be expected and what are the best means to be adopted under given circumstances.

The question may be approached from one of two different standpoints, namely, that of the general public, who are the sufferers from the smoke nuisance, and who have a right to demand that something be done to improve the atmospheres of our large towns; and, from the point of view of the persons who are directly responsible for the existence of the smoke, these being chiefly factory owners who make use of boiler or other furnaces in the processes of their manufactures. The latter may or may not be included in the former class, most frequently not. This must be regarded as one of the most potent causes of the indifference of many factory owners to the evils caused by their own unwillingness to try and improve the conditions of working or to spend the necessary money. A very large number of the owners of smoke-producing factories live in other neighbourhoods, where they may be free from the evil effects of their own smoke, and that of their fellow millowners. If they had to spend their lives in close proximity to their mills perhaps they would become a little more conscious of the existence of the smoky atmosphere. Of course this is not always the case; some millowners do live close to their mills, especially in the country districts, but it is here that the smoke becomes more distributed and its presence not so noticeable. But, at the same time, it is most extraordinary how a man can live within 100 yards of his mill and see day by day, as he cannot help doing, dense volumes of black smoke pouring from the top of the chimney of his mill and not take any steps to try and lessen the evil, if only for the sake of his own comfort and that of his immediate neighbours. The writer knows a case of this kind, where the owner of a large cotton mill lives in close proximity to the mill, which is one of the worst as regards smoke that the writer has seen. The smoke has been pouring out of the chimney for years and helping to blacken the country for miles round, soiling the grass even on the tops of the adjacent moors. This millowner is a most kind and philanthropic man; he takes the greatest interest in the welfare of his workpeople and in the neighbourhood generally; and yet he is apparently unwilling to consider the question of the emission of smoke from his mill chimney and to spend the necessary money on its improvement. There are unfortunately many such cases, and the fact remains that where a man is making money by running a factory he often becomes callous and indifferent to any results produced by his process of manufacture on the outside public, for the removal of which a certain sum of money would have to be expended. The same thing is found in the case of the alkali works and the fumes sent out, and, in a rather less harmful degree, in the pollution of rivers. This spirit of callousness is not confined to the manufacturers alone, but is found to be more or less universal. How many persons are there who substitute gas firing for coal fires in their houses because they think such a substitution will improve the atmosphere which their neighbours have to breathe? In most cases, unfortunately, the reason may be one of expense or labour, or simply a matter of personal convenience. There can be little doubt that it is this spirit of callousness which has allowed the smoke nuisance to assume such large proportions before any attempt has been made to put a stop to it. The task is now doubly difficult.

Much has been done and is being done towards the purifying of our town atmospheres, and, though the evil is still very rampant, a great deal of good has been effected by the various committees which have been at work, by the exhibitions of smoke appliances which have been held, and by the continuous agitation which is being carried on by a small minority. But the general public do not even yet seem to have grasped the smoke question in any degree of fulness, either as to the extent of the evil or to the possibilities of improvement which are at hand. The whole matter rests with the public, and it is for them to awake to the fact and to apply the remedies which the existing law provides and compel the producers of smoke to make use of such appliances and methods as have been proved to be beneficial in lessening the smoke emitted from boiler and other furnaces.

The present law is certainly defective in that it leaves too much to the individual and to local authorities. These local authorities and the justices of the peace who have to administer the law as it stands are in very many cases composed, if not of the factory owners themselves, at any rate of men of their own class and sympathies, and they are naturally not sufficiently severe in insisting on the absolute stoppage of the emission of black smoke, when it is proved that such stoppage is possible in the cases under consideration. The majority of millowners are indifferent to the periodical imposition of nominal fines, and would much rather pay these without demur, than go to the greater expense of equipping their factories with proper appliances. It is doubtful if very much permanent good will be effected until the law is amended and inspectors are appointed under Government in precisely the same way that the inspectors of alkali works are appointed. These inspectors should be men who are thoroughly trained engineers, with special knowledge on the subject of the combustion of fuel in furnaces of various kinds. The whole question might be placed in the hands of a department consisting of a number of these inspectors acting under a chief inspector. Probably if an inspector had charge of a large manufacturing district a number of sub-inspectors would have to be appointed, who would carry out the great bulk of the inspecting, which is now done by the smoke inspectors under the local authorities. A system such as this would render the enforcing of the law a matter for Government inspectors, who would be quite free from local influence and bias, and the class of men appointed would naturally be above anything in the shape of bribery. The inspectors would also, being men with a special knowledge of the best means of combustion, be able to advise the factory owners as to the best methods to be adopted in their special cases, and to recommend the use of definite appliances which their experience and knowledge told them would be advantageous. One does not see how this condition of things is to be brought about, but it is a matter for the public and, through them, for Parliament. It is to be hoped that something definite will be done before long, because the number of factory chimneys is continually increasing, and the longer the matter is allowed to proceed on the present lines the more difficult will be the work which comes afterwards.

But, apart entirely from the legal aspect of the case, assuming that a factory owner is desirous or is compelled by law to improve his furnaces as regards smoke emission, the next question which arises is, how may an improvement be effected with the best prospect of good results accruing, with the least possible strain on the pocket of the millowner, and, at the same time, with economical results at least as good as before? Much depends upon the circumstances surrounding the particular case in question, whether the remedy is to be temporary or permanent, partial or complete, whether the boiler—if it is a boiler—is a new one or an old one, and so on. The different remedies may be classed as follows:—

TEMPORARY AND PARTIAL.

Under this head are placed cases where it is desired to provide an effective remedy for smoke, to be applied to an existing hand-fired furnace without any great outlay.

1. *Careful Firing and Regulation of the Air Supply.*—This can hardly be strictly classed as a remedy, for it is a state of things which should exist at all times in hand-fired furnaces. There is no question that in a hand-fired furnace, where proper attention is given to the firing, such as by the use of side firing or alternate firing, and the careful use of fire door or air doors to admit the right quantity of supplementary air at the right time, there need be very little smoke produced, at any rate in objectionable quantities. Two conditions are necessary for this to be done, namely, there must be a good chimney draught, and the boiler must not be pressed for steam, with the result of hard firing.
2. *The Use of Smokeless Fuel.*—This is not always possible, but it may be noted that anthracite is practically smokeless, Welsh coal nearly so, while coke is quite smokeless. Where the coal is of necessity not one of these, by feeding alternately on the two sides of the fire as mentioned above, or allowing the coal to coke on the front of the furnace, before it is pushed on to

the body of the fire, with a due amount of care to the air supply, nearly smokeless combustion can be effected.

3. *The Application of Steam Jets above the Fire.*—When the draught is at all deficient and it is required to render the furnace smokeless without going to much expense a very good plan is to have a steam pipe inserted just above the fire, as in the Whittle device already described (p. 42). This will help the draught, and, if the jet is turned on each time stoking takes place and the door left open, both for about three to five minutes, it will be found that the fire will burn without smoke, except in very unusual cases. The cost of applying one of these jets is very small and the fixing interferes little with the work of the fireman. Of course it must be remembered that the satisfactory and economical working of this device depends on the fireman, and any negligence on his part may mean much smoke and the waste of a good deal of heat.
4. *Admission of Air at the Door, through a Special Valve, or at the Bridge.*—If the chimney draught is good an adjustable air valve in or above the fire door or at the bridge, to allow of the admission of supplementary air after firing or when raking, will do much to prevent the emission of smoke if properly used and not kept open when the fire is incandescent.

PERMANENT AND PARTIAL.

This is meant to refer to those cases where it is decided to apply some permanent remedy to a smoky hand-fired furnace, without introducing any radical changes in the system of firing.

1. *Automatic Admission of Supplementary Air.*—Several automatic appliances have been described in the foregoing pages, but there is not one on the market, so far as the writer is aware, which has been proved in all respects satisfactory, and has shown by its adoption and employment over a considerable period of time that it is able to do its work without having to be stopped for repairs. Several of these have shown great promise, but they have all developed some defects which have proved their undoing. In saying this the writer hopes he is doing no injustice to any of the many inventors who have approached this subject.
2. *The application of a forced draught grate,* such as that of Meldrum Bros., Mr. Granger, or Messrs. Mason. These are particularly well adapted for cases where either the natural draught is bad or it is desired to increase the output of the boiler. Smaller and cheaper coal can be used, thus effecting an economy, the draught is increased so as to improve the combustion, and by supplying air above the fire or at the bridge, either with or without an extra steam jet, the combustion *can* be made perfectly smokeless and at the same time economical.

PERMANENT AND COMPLETE.

Although the above devices if properly used can be made to burn the coal smokelessly, and at the same time economically, they one and all depend to some extent on the weakness of human nature, and cannot be regarded as perfect smoke burners unless they can be rendered automatic and independent of manual control. When, therefore, a new boiler is to be put in, or it is wished to make an existing boiler perfectly smokeless, some other method must be adopted.

Gas Firing.

The combustion of gaseous fuel is absolutely smokeless, except in the case of the high hydrogen gases, which are hardly ever used in this way. Gaseous firing may be used under one of several circumstances. There may be a supply of gas already at hand, yielded as the by-product of some other process, such as in the case of coke ovens, blast furnaces or other metallurgical furnaces. In these cases it is only necessary to make the small structural alterations in the boiler which may be required, and a smokeless fire will be obtained without any trouble. Where, however, such a supply of gas is not available, it must be specially prepared in some kind of gas producer, such as Wilson's, Dowson's or Mond's. The combustible gas can be cheaply made, and the first cost of the producer is not high, but it is only in certain kinds of plant that this kind of firing is economical, as things are at present. There ought to be several boilers, and they should be running continuously day and night, so as not to have to stop and start the producers. Where these conditions hold, gas firing can be made exceedingly convenient, for it is smokeless, the air supply can be adjusted to a nicety, and the furnaces require practically no attention.

Down-draught and Double Furnaces.

The down-draught furnaces in use in the United States and the double furnaces in use chiefly in Germany, seem to promise very good results both as regards smoke and economy. The principle which has already been described is the same in both, namely, the coking or volatilisation of the hydrocarbons at the front in such a way that they have to pass through an incandescent zone before reaching the flues, and in this way are completely consumed. In the down-draught furnaces this is done by two sets of bars, one above the other, the green fuel being fed on to the upper bars and the hydrocarbons having to pass downwards on to the lower set of bars before reaching the open flue. In the German furnaces combustion of the coal takes place between two sets of vertical bars, and the coal is fed in such a way that the coking is effected at the front of the boiler, and the hydrocarbons have to pass through an incandescent zone before reaching the flue. The principle is good, and reports of tests appear to be favourable, but too little is known of these furnaces in this country for us to be able to form a reliable opinion as to their merits from every point of view.

In the Murphy furnace, which has also been described, the same principle is made use of in a modified form. In all these furnaces, where the coking process is confined to the early portion of the fire, the combustion is practically smokeless.

Coking Mechanical Stokers.

When a new boiler is to be fitted with a smokeless furnace the *best kind to adopt is without doubt* some one of the several coking mechanical stokers which are made. These are best adapted for large boilers, either Lancashire or water tube, where the required supply of steam is to be uniform and continuous, and also in cases where the capacity of the boiler is ample for the work it has to do. The firing in all stokers of this class is smokeless, this being due to the principle mentioned above, the carrying out of the coking at the front of the furnace before the fuel has travelled any distance along the bars. A good mechanical stoker requires very little attention beyond the keeping the hopper full of coal of the right kind, that is, small and dry, and may be relied upon to burn uniformly and smokelessly with a good efficiency. Of course power is required to drive the mechanism, but the actual amount of this is small compared with that yielded by the engine which is supplied with steam from the boiler.

Dust Fuel Furnaces.

These are smokeless in their action, but they have hardly as yet passed sufficiently far beyond the experimental stage to be recommended for application to either existing or new boilers. Gaseous firing and mechanical stokers of the coking sort, and possibly double grate furnaces, are much more to be relied on as yet.

The means which have been recommended for adoption in certain cases are all well known and have been successfully tried and not found wanting. If the owner of a furnace or a number of these is compelled by law to adopt some means of consuming his smoke, or rather of not producing any; or on his own initiative desires to render his chimney smokeless, his best plan is to have his boiler thoroughly tested both for economy and smokelessness, and also to ascertain any specially important points bearing on these, such as chimney draught, air supply, and so on, and then to have the opinion of an expert who has had experience with cases of all kinds, and to take his advice as to the best means to be adopted. It is very little use to rely altogether on the opinions of makers of boiler appliances, as each one is sure to be to some extent biassed in favour of his own particular system. If the boiler owner gets a number of such opinions, he is sure to find himself in somewhat of a dilemma as to how to weigh the evidence which he has in this way obtained.

One thing is quite certain. If a boiler owner sincerely wishes to render his boilers smokeless he can do so, provided only that he is prepared to spend a certain amount of money. There are very few cases where an improvement cannot be effected, and where this is so it is the fault in most cases of the existing conditions.

Future Developments.

Such being the methods which are to be employed for the further diminution of the smoke nuisance, it only remains to try and form a just and fair estimate as to the effect which future developments in engineering science and enterprise are likely to have in furthering the cause of those who are so strongly in favour of a purer atmosphere in our towns. The tendency appears to be all in the right direction, and the outlook may be regarded as distinctly hopeful. And there are reasons for supposing that the increased purity of the atmosphere of manufacturing towns will be brought about in ways other than those which have been so strongly urged for the last ten or twenty years. As far as can be seen, too much reliance must not be placed on legal remedial measures, as the law on the smoke question now stands. Unless some drastic reform in the law is introduced by which the detection and prosecution of offenders is placed in more responsible hands than is the case at present, things may be expected to go on as now, and the newspapers filled with reports of the prosecution of numberless manufacturers, on whom are imposed small fines which are quite inadequate. If one of these manufacturers were to be told that he must either spend £50 on curing his smoke, or pay the same or a greater sum as a fine, much would be done towards the end which is so much to be desired.

Signs are not wanting that in several directions an improved state of things is approaching. In domestic cooking and heating alone great strides are being made in the use of gas instead of solid fuel, and the one thing that is required to give an impetus to this method of burning the fuel is a cheaper gas. Now that electric lighting is taking such a strong hold of the public mind, and may be expected in the course of a few years to be as universally used as has been coal gas in the past, the gas companies and local authorities having control of the manufacture of gas may be expected, in view of the greatly diminished consumption of illuminating gas, to push forward and develop the use of a second kind of gas which is adapted for heating purposes only. Such a gas can be made more cheaply than illuminating gas, and no doubt a great deal of the existing plant could be utilised for its manufacture and distribution. This is being done at the present time in the case of at least one town in the north of England; in this case both kinds of gas are being made and distributed simultaneously. Under the most favourable conditions the use of ordinary illuminating gas for cooking and heating is held to be economical when the price of the gas is not unusually high and all the circumstances are taken into account, such as labour saved, possibility of using gas fires only just when they are required, and the diminished amount of dirt produced in a house. Very few people, however, will believe that there is an economy unless they see a distinct reduction in their coal bill and gas bill combined, but with a cheaper gas this saving would be at once apparent, and a much more general adoption of gas fires and cooking stoves would follow. In the direction of the increased employment of gaseous fuel for domestic purposes we may then look for one of the purifying influences.

In electric heating and cooking we may look for another source of improvement, though this is a question for the more distant future, and must not be regarded as so certain as the last mentioned. These heaters, although somewhat wasteful as far as the conversion of electric energy into heat is concerned, are very economical in other ways. All the heat that is generated is used, there are no waste gases to be got rid of and to carry away part of the heat generated; like gas stoves they can be switched on and off at pleasure, and they can readily be moved about from one part of a room to another.

Gaseous fuel is being used to a much greater extent than heretofore for manufacturing purposes, where the conditions are suitable. It is being recognised by owners of coke ovens, blast furnaces, and metallurgical furnaces that the heat in what were formerly considered to be waste gases is capable of utilisation, and in very many cases this is being done. For general use for steam raising in boilers the use of specially prepared gaseous fuel is not, as far as present knowledge and experience go, suitable except in a very few cases, the chief reason against this being the fact that most boilers have to be worked for so many hours during the day and must be shut down during the night. Of course there are exceptions to this rule, but they form a small percentage of all the boilers in use.

Another direction in which there are great possibilities is in the increased use of gas engines in place of steam engines. By using a gas engine in place of a small steam engine a great cause of smoke is removed, for there is little doubt that small boilers, especially small vertical boilers, are much worse sinners as regards smoke than the larger boilers, and these are being very rapidly displaced by gas engines driven either with illuminating gas from a public supply or by cheap gas specially prepared for the purpose. But it is in the extended use of gas engines for large powers that the greatest hope lies. Each year as knowledge and experience grow and mechanical difficulties are overcome we find gas engines being made of larger and larger powers, and there is no doubt but that these will to a very large extent replace steam engines for very many purposes. The chief difficulty which has hindered a more rapid development in this direction has been due to the impossibility of making gas engines as easy to control as steam engines. These difficulties are being gradually overcome, but there are still difficulties about starting and stopping gas engines of large size, which make people very chary of using them in place of steam engines. In the larger sizes, especially when using Dowson or other special gas, the gas engine is a very economical heat engine, and under fair conditions can be made to compare very favourably with steam engines in this respect. The difficulty of control depends on the fact that a gas engine has no reserve of force. In the steam engine there is a boiler in which the steam can be kept at full pressure for use whenever desired, and it is only necessary to admit the steam into the cylinder of the engine to start it; whereas, in a gas engine, life, as it were, is extinct while the engine is not running, and some device must be employed to generate sufficient force to start the engine before anything can be done. Possibly this difficulty will be overcome by the use of pressure tanks capable of storing sufficient energy in the form of compressed air to start the engine at any moment.

Another source of satisfaction is to be found in the fact that many owners of boilers are making use of either forced draught to increase the output or are applying mechanical stokers. Of these latter the greater preference seems to be for the coking type, which is as it should be, as the coking kind are by far the better of the two from a smoke abatement point of view. It is quite a common thing to find a new installation of boilers being completely equipped with mechanical stokers and, in many cases, with a full set of conveying machinery for supplying these with the fuel. For hand-fired furnaces the various systems of forced draught are being greatly used, and these, although not necessarily smokeless in themselves, provide an abundant supply of air below the fire bars at a pressure above that of the atmosphere, and this makes it easy to adjust the supply of supplementary air which is needful both for economical combustion and for smokeless firing. In all probability the use of mechanical stokers will become much more general in the near future for both large and small boiler plants.

But the greatest cause of hope for a more permanent diminution of the smoke in the atmosphere lies in the fact that at the present time there are signs of a tendency towards centralisation in the development of power. For this we have to thank the advance which has been made in recent years in electrical science. Electricity has proved itself to be for most purposes the best means of transmitting power to a distance, and it is on account of this fact that there is a great opening for development of the centralisation of generating plants and the transmission of the power developed to distant points. The first use of electricity for the transmission of power to anything like a general extent was in the case of the telegraph, by which motion was given to the parts of a receiving instrument by means of certain currents sent along a line to a great distance from a transmitting instrument. This was followed by the telephone contemporaneously with the introduction of electric lighting, which has developed to such an enormous extent during the last seven or eight years.

At the present time (1901) the greatest and most noticeable development in the utilisation of electrical methods for transmitting power is in its use for working tram cars and, to a small extent, railway trains also. Here the current is generated in a central station, and is transmitted along conductors to all parts of the tram route, where it is picked up and made use of at any point by the moving cars. It is probably in connection with the working of cars by means of electric transmission that valuable experience has been gained, so as to enable schemes for the general transmission of much larger amounts of power to be made use of in America and in Europe, and, more recently, in this country also. At the Niagara Falls between fifty and a hundred thousand horse power are constantly being developed from the natural source of power presented by the Falls themselves. This power is used to drive dynamos and so generate electricity. The currents so produced are sent along conductors to towns many miles away, where they are made to drive numerous motors for supplying power for various industrial purposes. This is a typical power installation. The power is developed in bulk and at one point, and distributed piecemeal as it is wanted at various distant points. Similar installations are in use in other parts of America, and also on the continent of Europe. In our own country we have no natural supplies of water-power, except in a very few and insignificant instances, but we have an abundant source of power in our coalfields, and, though this source is by no means inexhaustible, it is sufficient to provide all the factories in this country with power for very many years to come. Three or four large schemes, involving the expenditure of several millions of pounds sterling, are in various stages of development at the present time. The course to be adopted provides an ideal solution to the smoke difficulty. In one of these schemes five generating stations are to be established in the coal districts of the north of England; the stations themselves are to be at the very pit mouths, so that no cost may be added to the price of the coal for carriage from the pit to the consumer. At these central generating stations engines and dynamos are to be provided with which to generate currents of electricity, which themselves are to be sent along lines of conductors to any point within radii of twenty miles.

At any of these points the current is to be again converted into available power by means of suitable motors, and the machinery is to be driven in this way. Thus, for instance, if a millowner requires power to drive his machinery, he has only to apply to the Power Company and the current will be brought to him, so that all he has to do is to provide one or more motors as may be most convenient, have these connected to the conductors, and he then has his power provided ready to hand. In a case of this sort there are no engines required, no boilers with their possibilities of smoke, and no workmen to attend to these appliances. Of course there will be a considerable outlay required on motors and accessories, but so far we have no means of comparing the cost of installation of the electrical plant with that of an equivalent engine and boiler plant. From the millowner's point of view the advantages presented by this arrangement are numerous and great. The only things he will have to concern himself with are the installation of his motors and accessory appliances, the care and upkeep of these, and he will have to pay a round sum each year for the current provided. There will be no boilers to attend to, to insure against explosion, and to cause dirt, the motors will probably occupy less space than the engines necessary to yield the same power, and, if a system of small separate motors is made use of, there need be no shafting to absorb power and waste oil; and, lastly, he will stand no chance of being prosecuted for the emission of black smoke. The only possible producers of smoke under this scheme are the generating stations. But, in all probability, the power will be developed by means of boilers whose furnaces are of the most approved kind, and the combustion may possibly be either supplied by gaseous fuel or mechanical stokers, or both. Some of the power is sure to be required day and night, and in this case gaseous fuel might be employed, whereas coking stokers could be used for those boilers which are only required during the day. This latter is only supposition. That these power installations are being prepared is perfectly true, and they should be welcomed by all those who are anxious to see our atmosphere clearer, as being the best solution—though not begun for that purpose—of the smoke difficulty that we have yet seen. It is thorough and complete, and, assuming that the great majority of factory owners within its influence avail themselves of the advantages offered, we may expect to see those neighbourhoods where this plan is adopted becoming less and less smoky as time goes on. Thus it is that the smoke trouble may be overcome automatically by means of systems adopted primarily in order to obtain more convenient development and transmission of the power to be used for driving the machinery of factories, and at the same time to put money into the pockets of the promoters and shareholders of the companies which have been formed to undertake the carrying out of the work. And there can be little doubt but that in the course of a few years, by reason of the improved methods of combustion, and more economical methods of utilising the energy latent in the fuel, we may expect to see an improved atmosphere and the life of our town inhabitants rendered more pleasant and healthy. If this comes to pass, and it may not be for a generation or more, it will be greatly due to the possibilities in power transmission which the recent advances in electrical science have made possible.

In the meantime there are many ways in which the combustion of coal on ordinary boiler furnaces may be rendered perfectly smokeless, either by the use of mechanical stokers or by the addition of some simple appliances to the furnaces as they stand. The two greatest hindrances to the introduction of these improvements are the owners who are unwilling to spend the necessary money, and the firemen who will not, in many cases, take the trouble to use the smoke-preventing appliances with which they may be provided; and often this neglect leads the owners to believe that they are useless, and the scrap heap is richer by an appliance which, if it had been properly used, might have rendered very good service in helping to reduce the smoke of the district in which it was being used. Firemen are among the most conservative class of men living. They are brought up and trained to use one class of furnace, and are extremely averse to trying to work a new form of furnace with which they may not be familiar in the first instance. The engineer in charge of the boilers may take endless trouble in explaining how a new appliance works, and the fireman himself may be quite ready to admit its value, but, in most cases, he seems quite unable to lift himself out of his old groove and to give a new appliance or furnace a fair chance and a fair trial. This may seem rather a sweeping statement to make, but most people who have had any experience in these matters will be ready to admit that in very many cases perfectly smokeless combustion would have been effected if it had not been for the incorrigible conservatism or obstinacy of a fireman. Most of this must be put down to ignorance of what is really happening during combustion, and if firemen could be provided with a little "technical education" in matters relating to the economical and smokeless combustion of fuel a vast amount of good might be expected to ensue. At the same time it must be admitted that there are numberless fanciful pieces of apparatus on the market which, though they are supposed to be "smoke burners," are worse than useless, even in the hands of careful and competent men. Among such may be mentioned "smoke washers," in which the smoke after being produced (which ought not to have happened) is washed by sprays of water, and in this way the carbon separated out; incandescent arches, air pipes through the water space, and many others, which, being wrong in principle, cannot be made to work well however much care is taken with them.

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